

VEGETATION, SOIL AND GRAZING RELATIONSHIPS IN THE MIDDELBURG DISTRICT OF THE EASTERN CAPE

By

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requirements for the Degree of Master of Science in the
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DECLARATION

I, the undersigned, hereby state that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

THESIS SUMMARY

Arid and semi-arid rangelands of the Nama-Karoo Biome are believed to have changed considerably since the arrival of domestic livestock in the veld. Severe grazing pressure is considered to be one of the prime factors responsible for the perceived degradation of vegetation and concurrent soil degradation. To understand the process of degradation and to make further recommendations for future veld restoration, a large-scale project was undertaken in the Eastern Cape. This project focused on the role that landscape heterogeneity plays in providing refuges for plant species. The key question asked in this project was: What role do these hypothetically less grazed mesas play in the conservation of rangelands in the Nama-Karoo of the Eastern Cape?

This study, a component of the larger project, investigated grazing and soil landscape gradients on- and off- the three mesas (Tafelberg, Folminkskop and Buffelskop) in the Middelburg District of the Eastern Cape, South Africa and the possible influences that they might have on the veld. The flats surrounding the mesas were mostly used as grazing camps in contrast to the plateaux of the mesas, which had varied levels of accessibility.

In the absence of direct observations, the primary objective of the study was to test the differential dung pellet abundance and impact of animals on different parts of the landscape. As such, dung pellet counts in this study were correlated with surrogates of soil physical properties including bare ground, trampling and litter cover. Variation in dung pellet density was found at the different habitats (flats, slopes and plateaux) of all mesas. The flats to the north-eastern and south-western of Tafelberg mesa were found to be more heavily utilized by livestock and herbivores, while the plateaux and south-eastern slopes of Folminkskop and Buffelskop were also utilized by grazers. The Tafelberg mesa was the only study site that was consistent with the hypothesis which stated that grazers would be less concentrated on the plateau compared to the surrounding flats due to its inaccessibility, whilst the high mean dung pellet density on the plateaux of the smaller Folminkskop and Buffelskop mesas due to easier access contradicted the original hypothesis. It appeared that dung pellet density did not clearly turn out to be an indicator of habitat use in this study, but showed where slopes and plateaux were accessible to herbivores, as in the case for the Buffelskop mesa, a higher

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abundance of dung pellets were found suggesting that higher intensities of habitat use took place.

During this study a strong pattern was observed of bare soil patches on the flats surrounding the mesas. There was a decrease in percentage of bare soil along the gradient of the three mesas with a high percentage of bare soil on the plateaux of the mesas. A significant correlation was found between bare soil and dung pellet density. However, the plateaux of Folminkskop and Buffelskop had a high percentage of bare soil compared to the plateau of Tafelberg mesa. Farmers mainly used these smaller mesas as grazing camps for their livestock and herbivores. A positive correlation between bare soil and litter cover of the different habitats was evident in this study. A lower percentage of litter cover at these sites was associated with a high percentage of bare soil. Litter is very important in a healthy vegetation community in terms of nutrient cycling and fertile patches.

A detailed assessment of soil chemical and physical properties would reveal, firstly, if vegetation change is better explained by soil or grazing effects and, secondly, if changes in soil have resulted from land use. Differences in macro- and micro-site variations between open-canopy (between shrubs) and closed-canopy (under shrubs) sites for each habitat were determined to differentiate between local scales due to land use and landscape scales due to geomorphology. The results suggested that carbon, phosphorus, calcium, magnesium, copper and manganese levels in soils at landscape scale better explain vegetation changes between habitats. At a local scale (open- and closed-canopy sites) land use was responsible for little changes in soils. Changes in only soil potassium, zinc and boron elements were actually a consequence of local scales due to land use. The soil nutrient content on the slopes appeared to be intermediate between the flats and plateaux of all three mesas. It appeared that dolerite capped Tafelberg and Folminkskop mesas had high silt and clay content, while Buffelskop (sandstone) mesa had a lower silt and clay content. Consequently, the texture and parent material of the soils contributed to the variations in soil nutrient composition between these mesas. High infiltration rate together with low nutrient content on the flats clearly showed that these flats, surrounding the mesas were degraded. The high infiltration rates were caused by high activity by livestock and other indigenous animals on the flats which breaks the surface crusting of bare soil and

improve infiltration. It was concluded that high levels of grazing at these sites have also altered the textural and soil properties.

Endozoochory dispersal and the deposition of dung pellets in areas of small patch disturbances play an important role in veld regeneration in degraded areas. Dung pellets collected from permanent study sites on the southeastern and northwestern flats and slopes, and all the study sites on the plateau of Tafelberg mesa, was sown in seedling trays, watered and monitored for seedling germination. Species list were then compared to below-ground soil seed bank data and above-ground vegetation data collected by other researchers at the same permanent study sites. Higher seedling percentages were recorded from dung pellets collected on the flats than on the plateau. A total of sixteen species were found to germinate in dung pellets collected on the flats compared to ten species germinating in dung pellets collected on the slopes and two species on the plateau of Tafelberg mesa. The seeds that germinated represent a variety of palatable grasses and shrub species. *Aristida* sp., *Eragrostis bicolor*, *Eragrostis chloromelas* and *Eragrostis obtusa* were palatable grasses recorded for dung pellets collected on the flats. Of the species recorded, *Aristida* sp., *Chenopodium* sp. and *Pentzia* sp. were found in dung pellets but were not recorded in parallel soil seed-bank and vegetation studies.

Successful restoration of veld conditions requires strict grazing management practices. Germination of seed in dung pellets might be considered to be a valuable means of indicating restoration potential and rangeland conditions for the identification of both degraded and conservation worthy areas. With appropriate land management skills and restoration measures, these challenges can be constructively and creatively faced.

TESISOPSOMMING

Daar word geglo dat die ariede en semi-ariëde weivelde van die Nama-Karoo bioom aansienlik verander het sedert die aankoms van mak lewende hawe in die veld. Swaar weidingsdruk word beskou as een van die vernaamste faktore verantwoordelik vir die waarneembare oorbeweiding van plantegroei en die gelyktydige grond agteruitgang (degradasie). Ten einde die proses van degradasie beter te verstaan, en om verdere aanbevelings te kan maak vir toekomstige veld herstel, is huidiglik 'n grootskaalse projek in die Oos-Kaap aan die gang oor die rol wat landskap ongeliksoortigheid speel in die voorsiening van skuiling aan plant spesies.

Hierdie studie ondersoek weiding en grondlandskap gradiënte (op en af) van die drie mesas (Tafelberg, Folminkskop en Buffelskop) in die Middelburg streek van die Oos-Kaap, Suid-Afrika en die moontlike invloed wat hierdie gradiënte op die veld het. Die vlaktes was meestal gebruik vir weidingskampe in teenstelling met die kruin van die mesas. Hierdie studie het duidelike patrone vir habitat-gebruik op die vlaktes, hange en kruine van al die mesas aangetoon. Die vraag wat gestel was, was watter rol speel hierdie hipoteties minder beweide mesas in die bewaring van weivelde in die Nama-Karoo van die Oos-Kaap?

Hierdie studie toets nie direk vir mis verspreiding as 'n plaasvervanger vir dier verspreiding in die landskap sedert werklike dier getalle nie oorweeg was nie. In die awesigheid van direkte waarneming, die primêre doelwit was om te toets die differensiaal misdigtheid en die impak van diere op verskillende dele van die landskap. Mis getalle in hierdie studie was gekorreleer met plaasvervangers van fisiese eienskappe insluitend onbedekte grond, vertrapping en droë plant materiaal decking. Variasie in misdigtheid was gevind by die verskillende habitate (vlaktes, hange en kruine) van al die mesas. Die vlaktes aan die noord-oostelike en suid-westelike kante van die Tafelberg mesa was meer hewig benut deur lewende hawe en hêrbivore, terwyl die kruine en suid-oostelike hange van Folminkskop en Buffelskop ook gebruik was deur weidende diere. Die Tafelberg mesa was die enigste studie area wat konsekwent was met die hipotese, terwyl die hoë gemiddeld misdigtheid op die kruine van die kleiner Folminkskop en Buffelskop mesas, as gevolg van makliker toegang weersprek die oorspronklike hipotese. Dit blyk dat misdigtheid duidelik opkom as 'n nie aanwyser habitat-gebruik in hierdie studie, maar wys wel waar hange en kruine toeganklik was vir

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herbivore, soos in die geval van Buffelskop mesa, oorfloed van mis was gevind wat voorstel dat hoër intensiteit van habitat-gebruik voorgekom het.

'n Duidelike patroon is waargeneem tydens hierdie studie van onbedekte grond areas op die vlaktes rondom mesas. Daar was 'n afname in persentasie onbedekte grond langs die gradiënt van die drie mesas. Die kruine van Folminkskop en Buffelskop toon hoër persentasies onbedekte grond in vergelyking met die kruin van die Tafelberg mesa. Daar is 'n betekenisvolle korrelasie tussen onbedekte grond en misdigtheid gevind. Boere gebruik hierdie kleiner mesas hoofsaaklik as weidingskampe vir hulle lewende hawe en herbivore. In hierdie studie is daar 'n positiewe korrelasie gevind tussen onbedekte grond en droë plant materiaal dekking van die verskillende habitate. Droë plantmateriaal bedekking speel 'n baie belangrik rol in 'n gesonde plant gemeenskap in terme van voedingsirkulering en vrugbare kolle.

'n Breedvoerige skatting van grond chemiese en fisiese eienskappe wou openbaar eerstens of plantegroei verandering beter verklaar word deur grond of weiding effekte en tweedens, of verandering in grond veroorsaak was deur land-gebruik. Verskille in makro- en mikroterrein-wisseling tussen oop-blaredak (tussenplantruimtes) en toe-blaredak (onderplantdekking) terreine vir elke habitat was bepaal om te onderskei tussen lokaal effek as gevolg van land-gebruik en landskap effek as gevolg van geomorfologie. Die resultate stel voor dat koolstof, fosfor, kalsium, magnesium, koper en mangaan vlakke in die grond by landskap effek beter plantegroei verandering tussen habitate verduidelik. By 'n lokaal effek (oop-en toe-blaredak terreine) land-gebruik was verantwoordelik vir min veranderinge in grond. Verandering in grond kalium, sink en boron elemente was werklik 'n gevolg van lokaal effek as gevolg van land-gebruik. Die nutriënt inhoud van grond op die hange blyk intermediêr te wees tussen die van die vlaktes en kruine van al drie mesas. Hierdie studie toon ook dat die geologie en topografie van hierdie mesas die grond tekstuur en nutriënt samestelling op en af van die mesas beïnvloed. Dit wil voorkom asof die dolerite bedekte Tafelberg en Folminkskop mesas, hoë slik en klei materiaal bevat, terwyl Buffelskop (sandsteen) mesa 'n laer slik en klei inhoud het. Gevolglik, tekstuur en ouer materiaal grond dra by tot die variasie in grond nutriënt samestelling tussen hierdie mesas. Hoë infiltrasie tempo tesame met lae voedingstof van die vlaktes dui daarop dat die vlaktes rondom die mesas oorbeweë was. Hierdie hoë infiltrasie tempo word veroorsaak deur hoë dierlike

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aktiwiteite op die vlaktes deur lewende hawe en ander inheemse diere wat die oppervlakke van onbedekte grond versteur en infiltrasie verbeter. Die gevolgtrekking word gemaak dat die hoë weidingsvlakke van hierdie terreine ook die tekstuur en ander grond eienskappe verander het.

Endozoochoreuse verspreiding en die mis-afsetting in gebiede van klein area-versteurings, speel 'n belangrike rol in veld herlewing in oorbeweide gebiede. Mis versamel by permanente studie terreine op die SO en NW vlaktes en hange, as ook al die studie terreine op die kruin van die Tafelberg mesa, is gesaai in saailing bakke, besproei en gekontroleer vir saailing ontkieming. 'n Lys van spesies is vergelyk met onder-grondse saadbank gegewens en bo-grondse plantegroei gegewens wat deur ander navorsers by dieselfde studie terreine versamel was. Hoër saailing persentasies is gevind vir mis wat op die vlaktes versamel is as op die kruine. 'n Totaal van sestien geïdentifiseerde spesies het uit die mis op die vlaktes ontkiem in vergelyking met die tien spesies wat ontkiem het uit die mis van die hange en twee spesies uit die mis van die kruin van Tafelberg mesa. Die ontkiemde saad verteenwoordig 'n verskeidenheid van vreetbare gras en struik spesies. *Aristida* sp., *Eragrostis bicolor*, *Eragrostis chloromelas* en *Eragrostis obtusa* is vreetbare grasse wat gevind was in die mis versamel op die vlaktes. Die spesies opname wys dat *Aristida* sp., *Chenopodium* sp. en *Pentzia* sp. Gevind was in die mis, maar nie in die parallelle grond saadbank en plantegroei studies nie.

Die suksesvolle herstel van veldtoestande vereis 'n streng weidingsbestuur toepassing. Die ontkieming van saad in mis kan beskou word as 'n bekostigbare manier om veld herstel potensiaal te bepaal, asook weiveld toestande vir die identifisering van beide degradasie en bewaring van waardevolle areas. Met gepaste veldbestuur vaardighede en herstel maatreels, kan hierdie uitdagings konstruktief en kreatief aangespreek word.

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Means \pm standard error for different pellet age classes (1= old; 2= intermediate; 3= fresh) with respect to their habitats for the mesas.35

Table 3.3

Means \pm standard error for trampling impact at different habitats of all mesas. Mean value 1 indicates evidence of trampling impact while mean value 0 indicates no trampling impact. Sample size (n) indicates the number of sampling sites at different habitats for the different mesas.35

Table 3.4

Means \pm standard error for percentage bare soil and percentage litter cover for the different habitats of the mesas. Sample size (n) indicates the number of sample sites for different habitats for the different mesas.38

Table 4.1

Means \pm standard error macro-nutrients of soils removed from open- and closed-canopy sites at different habitats from all three mesas in the Middelburg District of the Eastern Cape. The units used to express concentration of each macro-nutrients were Carbon= C (%); Phosphorus= P (mg/kg); Potassium= K (mg/kg); Calcium= Ca (mg/kg); Magnesium= Mg (mg/kg); Copper= Cu (mg/kg).

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Table 4.2

Means \pm standard error of micro-nutrients of soil samples removed from micro-sites (open-and closed-canopy) at different habitats (flats, slopes, plateaux) of all three mesas in the Middelburg District of the Eastern Cape. The units used the express concentration of each micro-nutrients were Zinc= Zn (mg/kg); Manganese= Mn (mg/kg); Boron= B (mg/kg) removed from open- and closed-canopy sites at different habitats for all three mesas.....80

Table 5.1

List of families, with the number of genera and species identified to date of writing. The "unidentified species" are those, as yet unidentified to distinct species level, that are possibly duplicates but which may be separate species. It also includes those plants that have not been identified categorically to family level.104

Table 5.2

Number of seedlings of species identified to date of writing. Data also represents the locality (flats, slopes and plateaux) from which dung pellet samples were removed on- and off- Tafelberg mesa.106

Table 5.3

Characteristics of plant species identified from seedlings emerging in dung pellet samples of mammals foraging on- and off- Tafelberg mesa with alien species that have been highlighted.107

Table 5.4

Table indicates relative abundance (% RA) of each plant species per habitat. Numbers 1, 2, and 3 indicate the following: 1= RA recorded of species in dung pellet emergence study; 2= RA recorded of species in above-ground vegetation study (Pienaar, 2002); 3= RA recorded of species in below-ground vegetation study (Jones, 2001).109

Chapter 1: Introduction

The variability in the Karoo landscape is unique with mesas being a common topographic feature (King 1942). Mesas are table-topped hills with relatively steep slopes and in some cases inaccessible plateaux. They are distinguished from neighboring mountain ranges in that, as discrete entities rising from surrounding plains (flat areas), they are effectively geological, topographical and ecological “islands”. The premise of this research study is that mesas may provide examples of habitats where the vegetation has been less impacted by the animals compared to those on the flats. The discussion focuses on the conceptual model that mesas act as conservation islands with less degradation than surrounding flats.

1.1 Perceived deterioration in the Nama-Karoo Biome

The Karoo Biome is the largest and most characteristically South African of our extremely diverse terrestrial ecosystems (Venter *et al.* 1986; Palmer and Hoffman 1997). The biome is divided into a winter rainfall Succulent Karoo Biome and a summer rainfall Nama-Karoo Biome. These biomes, as well as the desert biome of Namibia, comprise the Karoo-Namib Region (Werger 1978; White 1978). The Nama-Karoo Biome is located on the central plateau of the Cape Province, the south-western Orange Free State and the southern interior of Namibia (Rutherford and Westfall 1986).

The perceived deterioration of Nama-Karoo vegetation is largely a result of overgrazing by livestock, over stocking, incorrect management systems as well as extreme climatic conditions (Acocks 1953; Milton 1994; Roux and Vorster 1983; Tainton 1972). Inappropriate land management and a policy for sustained use of Nama-Karoo vegetation have also not helped this situation. In places, veld condition has become so severely impacted that the degraded veld may never be able to recover without active restoration (Wiegand and Milton 1996). The lack of scientific understanding of the Nama-Karoo ecosystem has also resulted in inappropriate land management (Bosch 1988). It is generally accepted that the vegetation of the Nama-Karoo Biome recovers at a slow rate even with appropriate sustainable management (Milton *et al.* 1994). Appropriate land management practices need to be developed in such sensitive arid zones since less than 1% of the biome is formally conserved in protected areas (Low and Rebelo 1996).

The consequences of continued and inappropriate veld management have resulted in a reduction of palatable plant species and an increase in unpalatable and other undesirable species (Acocks 1953; Hoffman *et al.* 1999; Milton and Hoffman 1994). The latter includes

invasive alien species such as *Atriplex semibaccata*, which may increase soil salinity levels to the detriment of indigenous species (Milton *et al.* 1999). Other changes include an increase in thorny, spinescent indigenous species such as *Rhigozum trichotomum* and other unpalatable or undesirable indigenous species such as *Chrysocoma ciliata* and *Gnidia polycephala* (Le Roux *et al.* 1994). Further, soil-stored seed banks of desirable plant species may have become depleted over a period of time through excessive grazing of plant material prior to flowering or successful seed set; loss of seed through seed predation; loss of germinated seedlings during drought following brief rainfall events; and, through natural loss of seed viability (Jones 2000; Louda 1989; Parker *et al.* 1989).

Inappropriate livestock levels not only affect the reproductive biology and competitive balance of the vegetation but also impact soils. Trampling and other forms of soil disturbance can, if too intense, result in increased soil degradation (Barrow 1991). According to Tongway and Hindley (1995), soil forms the fundamental resource of vegetation change and can be associated with changes in soil surface characteristics. If vegetation alone is monitored, it will not reveal the full interactions between grazing animals and vegetation and whether the soil as a habitat for pasture plants has been altered. Soil surface condition provides significant information as to rangeland status (Tongway and Hindley 1995). Condition and trends of rangelands can now be assessed not only with respect to species composition and cover, but also in terms of the more fundamental changes in the inherent stability of the system such as land condition (Tongway and Hindley 1995). This is important given the need to predict rather than simply describe changes in land condition. Tongway and Hindley (1995) also investigated soil surface condition (and their application to the management of the semi-arid grasslands/ shrublands of Middelburg, Eastern Cape).

1.2 The utilization of mesas

It is believed that the vegetation of flats (that are interspersed with mesas providing topographic variations to the otherwise flat landscape) in the Karoo has changed considerably, since the arrival of livestock in the veld (Roux and Vorster 1983). The flats have been and continue to be used as grazing camps whereas mesa plateaux are less intensively used due to their inaccessibility. Animals can move up the slopes until gradients become too steep or unstable and the habitat essentially becomes unavailable to them. In contrast to Joubert (1997), suggesting that steeper slopes are more likely to be used than the flatter slopes, Defosse *et al.* (1997) argued that steep slopes may in fact prevent livestock and herbivores from having access to the plateaux due to the topography and the lack of drinking water for the animals.

The concept of palatable versus unpalatable plant species also forms an important factor in these situations. Dominance of unpalatable plants on the flat areas could drive animals to move up the slopes in search of more palatable plant species. However, the extra energy that the grazers have to expend in climbing steep slopes and the discomfort endured, may on the other hand discourage grazers, and this could afford some measure of protection from overgrazing to these areas (Bosch and Janse van Rensburg 1987; Bosch and Gauch 1991).

1.3 Grassland Vegetation and Herbivores - co-evolved systems

Grazing is not always considered to be bad since grasslands have co-evolved with grazers (McNaughton 1979b; McNaughton 1984; Stebbins 1981). In the absence of these grazers decreasing species richness is likely to occur (McNaughton 1976). According to Wallace *et al.* (1984), grass from heavily grazed grasslands of the Serengeti ecosystem in Tanzania have long coevolved with grazers and are most likely to be mutualistically associated with them. Thus an absence of grazing could result in the loss of these species. Grazing is an essential component for the maintenance of biodiversity in arid grassland dominated ecosystems.

1.4 Vegetation changes in the Karoo

Domestic livestock are currently the principal grazers and browsers over most of the Karoo region (Owen-Smith and Danckwerts 1997) and over-stocking of sheep and goats was the main cause of degradation in the region (Tainton 1972). Herbivores not only have direct impact on vegetation composition, but also affect vegetation in other ways by trampling or breaking plants and disturbing soils. For the semi-arid Karoo, the theory of vegetation change suggests that as a result of European agricultural practices, the eastern Karoo areas have been altered from perennial grassland to a dwarf shrubland (Roux and Theron 1987; Tidmarsh 1948). The Karoo is thus considered less productive than it used to be, in terms of its carrying capacity (Hoffman and Cowling 1990). According to William Asher (pers. com.), a local farmer, there has been a decline of large stock units (LSU/ 15 ha) over time for the Middelburg area. At present the LSU/ 15 ha for the Middelburg area is between 1 and 2. Severe grazing pressure, owing to high stocking levels of cattle and sheep, is commonly believed to have been the prime factor responsible for the perceived degradation of the vegetation component in the Nama-Karoo Biomes (Acocks 1953; Owen-Smith and Danckwerts 1997; Roux and Vorster 1983). Sheep, especially, favour higher-quality plant parts, selecting lateral tillers and concentrating their feeding in particular localities. Therefore, their grazing effects may be more damaging to plants than those caused by equivalent stocking levels of cattle such as Nguni (Tainton 1972). Acocks (1953) suggests

that the continuous selective grazing habit of domestic stock depletes root reserves, particularly for perennial grasses. Acocks (1953) believed that vegetation in the eastern Karoo has changed from a perennial palatable grassveld to a less productive karroid shrubland, largely devoid of grasses (Tidmarsh 1948, Klintworth 1949). Hoffman and Cowling (1990) found little support for this and suggested that perennial grasses may not have dominated the pre-colonial eastern Karoo and that fluctuations and seasonal rainfall effects might be responsible for much of the perceived vegetation change in the Karoo. This is supported by Danckwerts and Stuart-Hill (1988), who suggested for the Karoo region that withdrawing grazing livestock in an area for at least six months after the end of a drought, would allow for the recovery of palatable grasses. This assumes that soil conditions are still favourable and soil seed banks are present. The severe loss of seed output by grazing of some plant species (Milton 1994) implies that even moderate grazing of this vegetation can lead to deterioration of the small seed bank of existing persistent and relatively desirable plant species (Jones 2000). There is no doubt that some form of vegetation change has occurred in places in the eastern Karoo. However the level to which this has happened probably varies over the landscape due to past management practices.

In the Nama-Karoo Biome, many farms have been subjected to diverse management practices and land use regimes and stocking, has often taken place at unsustainable rates. The effects of overstocking become amplified during times of below average rainfall (Bousman and Scott 1994). The role of veld management systems is to provide the feedback through which these veld management practices, such as non-selective and selective grazing, are monitored for improved veld conditions (Teague *et al.* 1981). If animals are stocked at low densities in a large camp, they only select the most palatable plant species and if left in that camp for a long time they will regularly return to the young regrowth of the grazed plants (Danckwerts 1987). Less palatable and unpalatable grasses and shrubs eventually dominate the vegetation. This can be prevented in two ways: by forcing grazers to graze non-selectively (NSG) through heavy grazing pressure or by removing grazers from the veld before they graze regrowth. Therefore, NSG can be used as a grazing system that reduces selective defoliation by forcing grazers to eat more species, including the less palatable ones. NSG is important because it increased germination and emergence of seedlings, and stimulate aboveground grass production, and flower and shoot production of dominant shrub species (Beukes 1999). The farmers in the Middelburg District commonly practice NSG on their farms through high stocking rates followed by long rest periods.

1.5 Rationale for research study

The underlying rationale for this research study is embraced by the broader project funded by the European Union and the NRF focusing on the “Restoration of degraded Nama-Karoo: the role of conservation islands”. The primary motivation of this Umbrella project was to assess the value of mesas in the area as conservation islands, and their potential use in restoration efforts. What role do these hypothetically less grazed islands play in the conservation of rangelands in the Karoo region of the Eastern Cape? Some relief of past poorly managed systems is offered by the presence of mesas in the landscape that are thought to be less impacted by farming practices. Using vegetation indicators, these mesas appear to be less degraded and have been identified as retreats for certain species (Burke *et al.* 2002; Pienaar 2002; Jones 2000).

1.6 Aim of research study

The focus of this thesis is on mesas in the Middelburg District of the Eastern Cape. The overriding aim was to determine if mesas act as conservation islands with less degradation than surrounding flats. Given the topographic variability of the study area, the idea then was to specifically focus on habitat utilization over altitudinal gradients (i.e. mesas and surrounding flats).

Figure 1.1 is a schematic diagram of the research framework. This diagram illustrates the three experimental conditions to determine whether mesas are less degraded than the surrounding flats; Tafelberg mesa, Folminkskop and Buffelskop. The plateaux of both Tafelberg and Folminkskop are fenced just below the dolerite cap of the mesas. Buffelskop had no fencing and was mainly comprised of sandstone. An issue not identified at the beginning of the study was the need of dung pellet separation between indigenous and domestic animals because of dung pellet identification difficulties. Indigenous animals mainly grazed the plateaux of Tafelberg and Folminkskop mesas, while both domestic and indigenous animals grazed Buffelskop mesa. The underlying assumption then was that dung pellet found on the plateaux of Tafelberg and Folminkskop mesas were mainly that produced by indigenous animals while those found on the slopes and flats of these mesas were from domestic animals. In the case of the Buffelskop mesa, dung pellet from domestic and indigenous animals may be found on the plateau and slopes, while dung pellets from domestic animals dominate the flats. Furthermore, this study does not directly test for dung pellet distribution as a surrogate for animal distribution in the landscape since actual animal numbers were never considered. In the absence of direct observations, the primary objective was to test the differential abundance and impact of animals on different parts of the landscape. As such, dung pellet counts in this study were correlated with surrogates of soil physical properties including bare ground, trampling and litter cover. The apparent limitations

in using these surrogates are that the resultant bare ground may easily be masked by competitive displacement between different plant species. Trampling also is a subjective assessment based on evidence of animal footpaths and the presence of damaged and grazed plants. A detailed assessment of soil chemistry would reveal firstly if vegetation change is better explained by soil or grazing effects and secondly, if changes in soil have resulted from land use. Differences in macro- and micro-elements of soil between open and closed canopy sites for each habitat were determined to differentiate between local scales due to land use and landscape scales due to geomorphology. The germination of seed found in dung pellet was only determined for the Tafelberg mesa as a possible method for future restoration attempts. This is the motive underlying the anticipation to stabilise slopes against soil run-off and restore degraded areas in the Middelburg District.

1.7 Specific objectives of the research study

The following objectives were addressed in the Middelburg District of the Eastern Cape and organised as follows:

Chapter 2 : To provide a description of the physical environment and biological characteristics of the study area as well as a description of the layout of the research study sites.

Chapter 3 : (a) To investigate if dung pellets can be used as a possible indicator of habitat use by grazers and degradation. I postulated that habitat use by grazers would be less concentrated on the plateaux of mesas compared to the surrounding flats due to its relative inaccessibility.

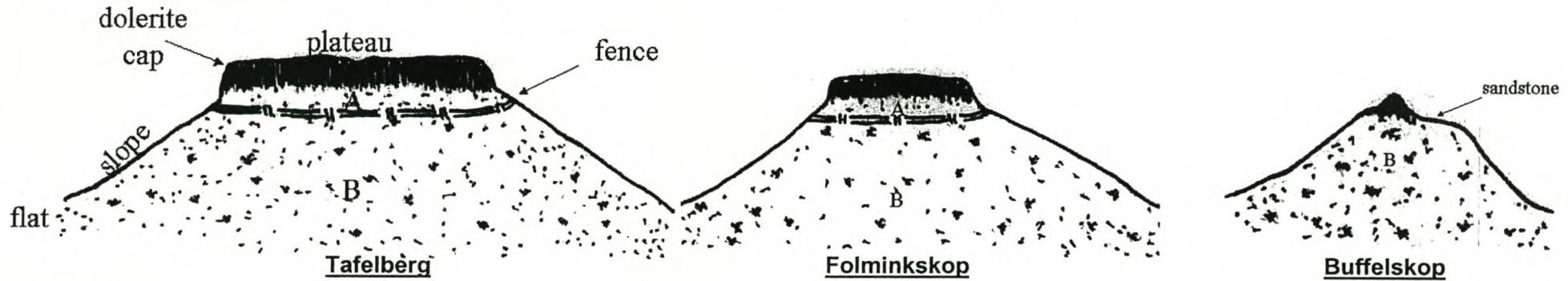
(b) To compare different habitat use by grazing animals using dung pellet density, trampling, bare ground and litter cover as indicators of habitat use and degradation.

Chapter 4 : To determine differences in macro- and micro-elements of soil between open- and closed-canopy sites at different parts of the landscape to differentiate between local scales due to land use and landscape scales due to geomorphology.

Chapter 5 : To determine if seed germinated from dung pellet samples may be used as an ingredient for restoration in degraded areas. I postulated that dung pellet seed germination could be used as a method for future restoration efforts in managing degraded veld in the Middelburg District.

IN THE ABSENCE OF DIRECT OBSERVATIONS

Experimental conditions



Animals: A = indigenous
B = domestic & indigenous

Dung pellet distribution

*domestic
+indigenous

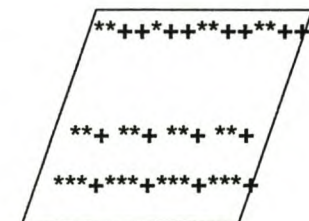
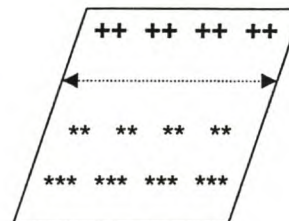
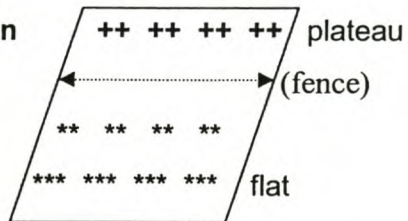


Figure 1.1: Conceptual model of the three experimental conditions (Tafelberg, Folminkskop and Buffelskop) in the absence of direct observations. Dung pellet distribution, soil-physical (bare soil and trampling) and soil-chemical (macro- and micro elements) were determined at these mesas. Arrows indicates high or low dung pellet density, physical and chemical properties over the three mesas. Dung pellet density is represented with plus (+) and asterisk (*) symbols. This model also illustrates dung pellet germination experiment carried out for Tafelberg mesa for future restoration.

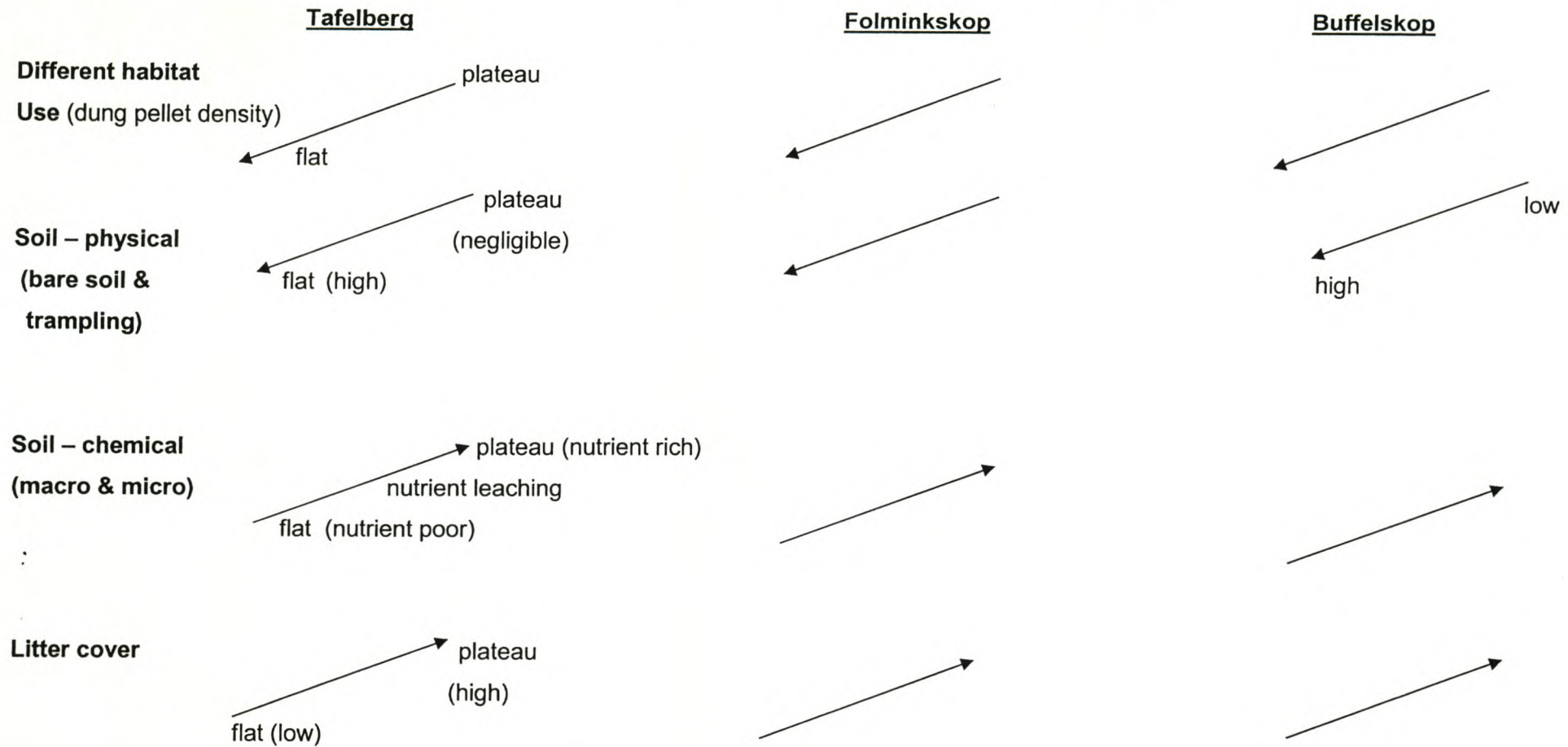


Figure 1.1 (Cont): Conceptual model of the three experimental conditions (Tafelberg, Folminkskop and Buffelskop) in the absence of direct observations. Dung pellet distribution, soil-physical (bare soil and trampling) and soil-chemical (macro- and micro elements) were determined at these mesas. Arrows indicates high or low dung pellet density, physical and chemical properties over the three mesas. Dung pellet density are represented with plus (+) and asterisk (*) symbols. This model also illustrates dung pellet germination experiment carried out for Tafelberg mesa for future restoration.

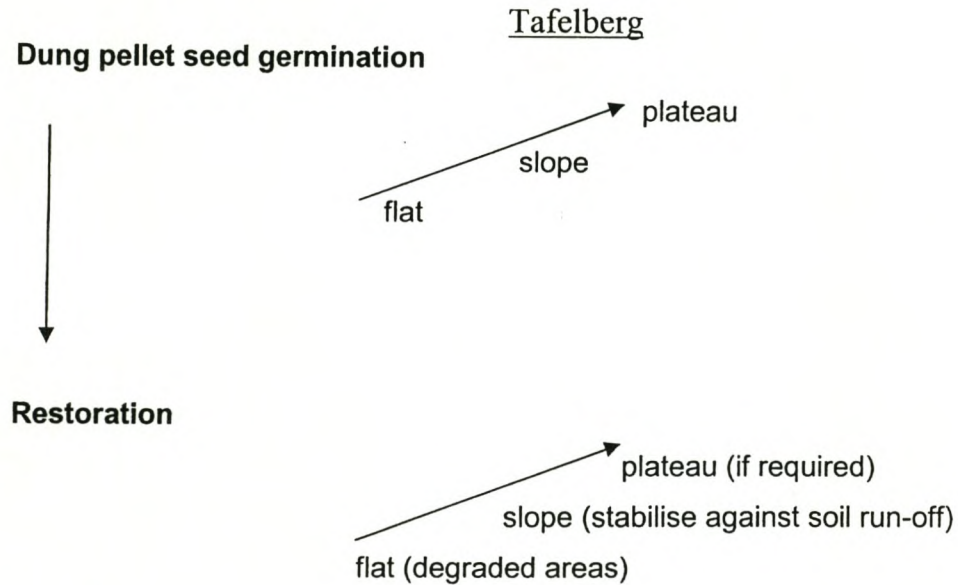


Figure 1.1 (Cont): Conceptual model of the three experimental conditions (Tafelberg, Folminkskop and Buffelskop) in the absence of direct observations. Dung pellet distribution, soil-physical (bare soil and trampling) and soil-chemical (macro- and micro elements) were determined at these mesas. Arrows indicates high or low dung pellet density, physical and chemical properties over the three mesas. Dung pellet density are represented with plus (+) and asterisk (*) symbols. This model also illustrates dung pellet germination experiment carried out for Tafelberg mesa for future restoration.

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Chapter 2: Location and description of study area

2.1 Location

The study sites (Tafelberg, Folminkskop and Buffelskop) are located in the semi-arid region of the Middelburg magisterial District and forms part of the commercial farming system in the Eastern Cape of South Africa. These mesas lie approximately 25 kilometers north-west of the Middelburg town, between latitudes 31°33'S and 31°40'S and longitudes 25°05'E and 25°15'E (Figure 2.1). The research study focused on the plateaux, slopes and surrounding flats of the three mesas.

2.2 Topography

The topography of the research study area is typical to Karoo landscape characteristic of much of the Nama-Karoo Biome (Low & Rebelo 1996); extensive flats dotted with mesas of varying altitudes that rise from the surrounding flats. The Nama-Karoo is part of a large interior basin drained by ephemeral rivers (e.g. Great fish). Folminkskop (1400 m) and Buffelskop (1400 m) are 200 m lower than Tafelberg (1600 m). Tafelberg were 450 m above surroundings while Folminkskop and Buffelskop were 200 m above surroundings. Tafelberg was much higher (250 m higher) than the other two mesas.

Drainage lines and seasonal streambeds, flood plains and ephemeral seeps are clearly visible, particularly on the flats surrounding the three mesas. Several small ravines allow access to the top of the three mesas.

2.3 Geology

The primary geology of the study area includes dolerite, mudstone and sandstone mesas that are surrounded by low-lying flats of alluvial and colluvial material. These mesas are remnants of an eroded African surface and are well known for their dolerite caps with fine-grained sand stone and red and green-gray, mudstone slopes (Geological Survey 1996). The dolerite is hard, but when it erodes it exposes the softer sediments that erode more quickly. In some situations these caps have completely eroded away of which Buffelskop is a classical example of such mesas (Figure 2.2). Both Tafelberg and Folminkskop are capped with dolerite whilst Buffelskop, is dominated by sandstone. Variations of soil nutrients are associated with soils derived from mudstone and sandstone. Calcrete is present on the flats surrounding the Tafelberg mesa. Soils on the

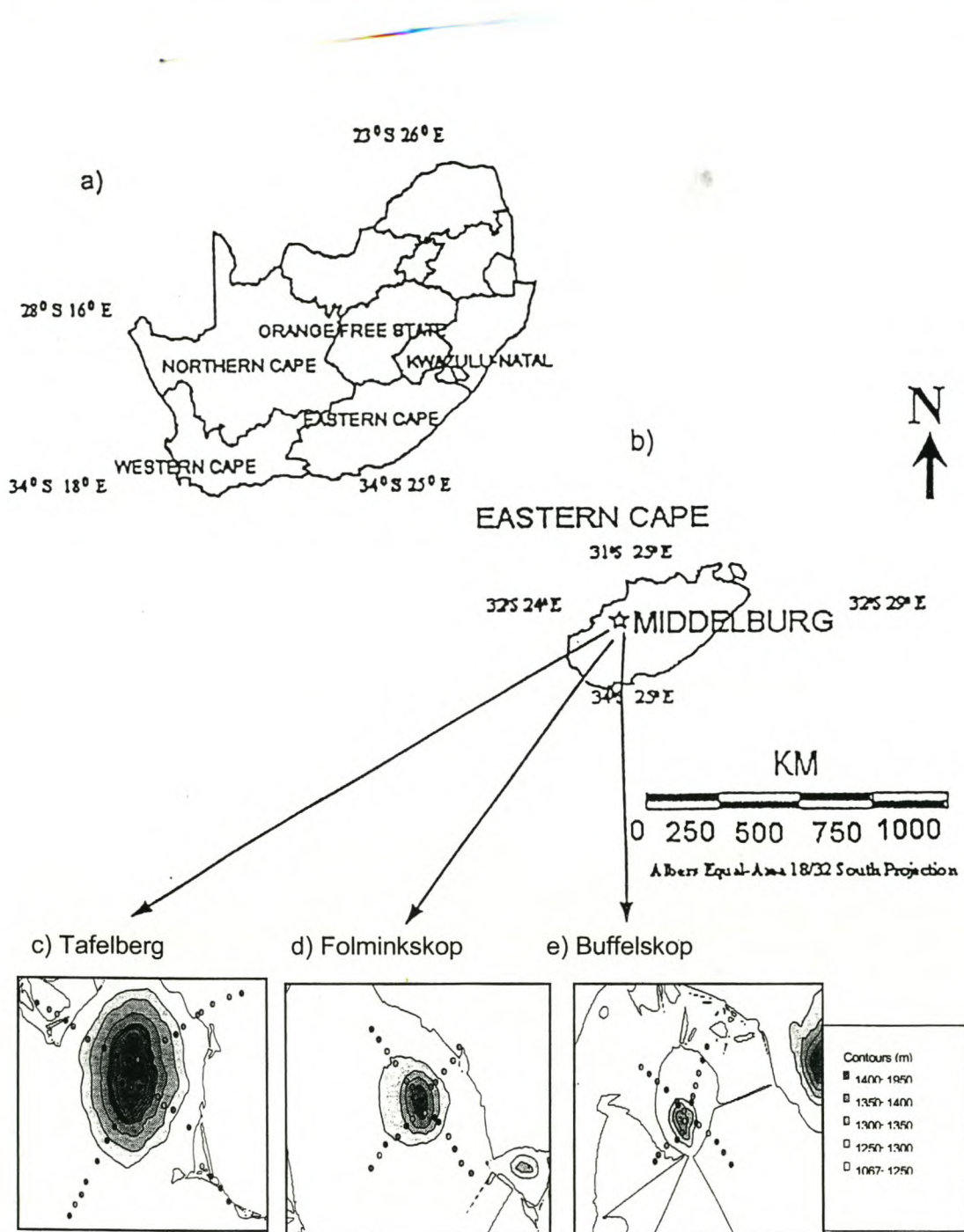


Figure 2.1: Schematic representation of the locality of the three mesas. a) Map of south Africa indicating locality of the Eastern Cape Province; b) Locality of Middelburg within the Eastern Cape; c) Schematic map of Tafelberg; d) Folminkskop; e) Buffelskop. Dots represent the locality of permanent study sites over the landscape.

flats, slopes and plateaux are mainly shallow as described for the Karoo region by Ellis and Lambrechts (1986).

2.4 Climate

The study area receives regular summer rains, but these are unpredictable in terms of occurrence, intensity and duration (Hoffman and Cowling 1987). The annual mean rainfall for the area is 360 mm with 15% falling in Spring (months), 30% falling during summer (October to March), 50% during autumn and 5% in winter (Data obtained from Grootfontein Agricultural College). Rainfall across the karoo decreases from east to west and from north to south (Desmet and Cowling 1999). Rainfall variability, as described by the coefficient of variation (CV) of annual rainfall, follows a similar trend. Generally, CV decreases with increasing mean annual rainfall (Fisher 1994; Hoffman and Cowling 1987). The CV for the study area is 341 ± 115 mm/year. According to Bousman and Scott (1994), there is a strong link between grass-shrub cycles and rainfall variability.

2.5 Temperature

The study area experiences an average temperature of 20.4 °C during January and 5.5 °C during July (Figure 2.3). There is a strong temperature gradient across the district, with the temperature range increasing with elevation (Palmer and Hoffman 1997). The mean maximum temperatures are often in the high thirties (38 °C). December to February is the hottest months (Figure 2.3). The mean minimum temperatures may reach below 0 °C in winter, with the coldest period between May to July (Figure 2.3). Frost is a fairly regular occurrence throughout the Nama-Karoo (Hoffman and Cowling 1987) and is common in the study area during winter months.

a)



b)



Figure 2.2: Photographs of the mesas in the study locality. a) Photo of Tafelberg mesa from the southeast aspect while photo (b) shows two smaller mesas, Folminkskop (middle) and Buffelskop (far left background) taken from the northwest aspect on top of Tafelberg.

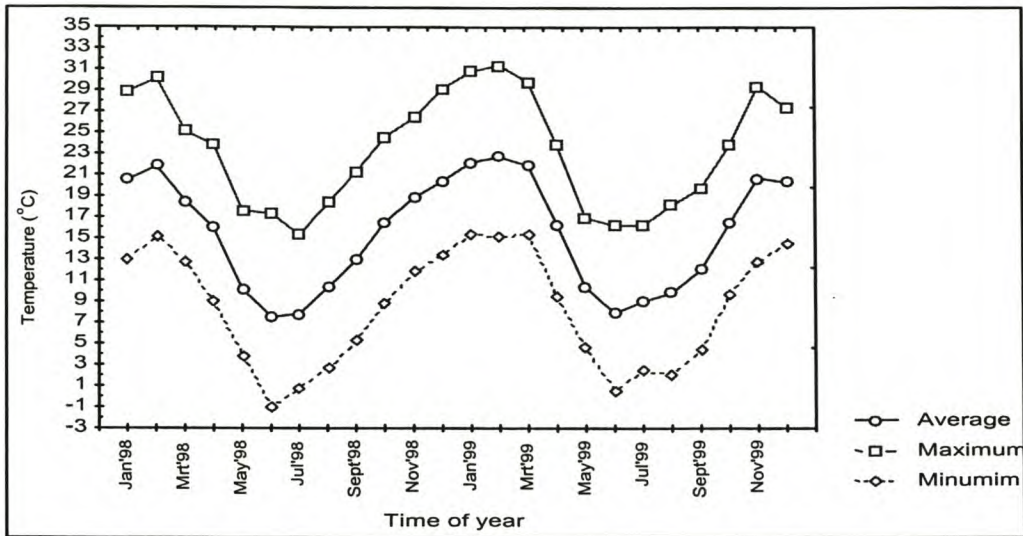


Figure 2.3: Average, maximum and minimum temperatures (°C) for the Middelburg region in the Eastern Cape from January 1998 to December 1999. Data were obtained from the South African Weather Bureau.

2.6 Vegetation

Acocks (1953) defined the vegetation of the Middelburg District as a mix of sweet/sour grassveld Karoo and dwarf shrublands (Rutherford and Westfall 1988). Palmer and Hoffman (1997) defined the vegetation type as “Grassy dwarf shrubland”. Areas on the flats of all three mesas have been degraded to the point where vegetation cover is sparse and the eroded surface resembles bare soil patches (Pienaar 2002). Degradation of this veld type has caused unpalatable grasses to dominate in more recent years (Acocks 1953). Dominant grasses include *Eragrostis lehmanniana*, *Aristida* spp. (steekgras), *Sporobolus* spp., while *Themeda triandra* is scattered throughout, its presence depending on the grazing history. The principal shrub species on the flats is *Chrysocoma ciliata*. This species can cause “kaalsiekte” in lambs of ewes that graze on the flowers (Le Roux *et al.* 1994) and is a clear indication of degradation.

Tafelberg plateau is dominated by *T. triandra* whereas the plateau of Folminkskop was dominated by *Enneapogon scoparius* and *Felicia filifolia* while *Aristida diffusa* is dominant on the plateau of Buffelskop (Pienaar 2002).

Vegetation composition and distribution is often influenced by the distribution, size and shape of the different landforms. The distribution and composition of communities across the Middelburg District were mainly attributed to a soil-moisture gradient (Pienaar 2002). Plant communities were found to be distinctly different in the different habitats (flats, slopes and plateaux) associated with mesas and their surroundings (Pienaar 2002). Mesas are distinctly different in plant composition to the surrounding flats, with no shared communities between mesas and their surroundings (Pienaar 2002). Genera such as *Carissa*, *Diospyros*, *Euclea*, *Rhus*, *Euryops* and *Maytenus* were restricted to mesa habitats and were absent from all flats. Species shared between flats and mesas were *Eragrostis obtusa*, *Felicia muricata*, *F. ovata* and *Pentzia incana*. These differences probably existed before the impact of domestic livestock, but overgrazing has likely exacerbated the differences. Drainage lines that cross the landscape support distinct communities of phreatophytic woody shrubs.

2.7 Land use

More than 80% of land in the karoo currently belongs to private owners where extensive sheep and goat, and to a lesser extent cattle, farming on natural rangeland remains the major agricultural practice (Hoffman *et al.* 1999). Because domestic livestock have been selected for a variety of production and behavioral traits, indigenous ungulates are unable to compete, in terms of productivity, under these intensive farming systems (Skinner *et al.* 1986). The commercial livestock production system applicable to the three study sites (incorporating the production, reproduction, marketing and range management aspects of the livestock industry) revolves mostly around extensive wool and mutton production. Approximately one quarter of the total surface area of the Tafelberg mesa was also grazed by cattle. The current rangeland management system of the three mesas was characterized by rotational grazing for short periods to allow plants to recover from grazing.

2.8 Description of study sites

A total of thirty-eight, 30 x 5 m permanent study sites were established on Tafelberg mesa and two smaller mesas (Folminkskop and Buffelskop). All the study sites were marked with permanent metal markers and geographical co-ordinates were recorded, enabling re-visitation (Table 2.1). Georeference was done using a sub-meter real time differential GPS for exact geographical positions of sites (Goos 1990). The study sites

were located at appropriate intervals on the plateaux, slopes and flats for all three mesas. The study sites were located along the four compass half points (SE = south-east, NE = north-east, NW = north-west and SW = south-west) and radiated from the slopes unto the flats to a distance of about one kilometer from the base of each mesa. Each permanent study site was subdivided into six, 5 x 5 m plots for sampling purposes. These six plots consisted of three plots reserved for vegetation sampling (Pienaar 2002) and three plots for seed bank sampling (Jones 2000) (Figure 2.4). Only the vegetation plots were used in this study. A total of 16 permanent study sites were demarcated on the flats and 16 permanent study sites on the slopes of Tafelberg. Six sites were demarcated on the top of Tafelberg. The distance between each permanent study site was approximately 300 meters apart. A total of 16 permanent study sites were demarcated on the flats and eight on the slopes of Folminkskop and Buffelskop. Three permanent study sites were demarcated on the plateau of Folminkskop while two sites were established on Buffelskop.

Table 2.1: Detailed location information for all permanent study sites. Latitude and longitude data are presented in decimal degrees.

Mesa	Site code	Habitat	Longitude	Latitude
Tafelberg	FNW1 (furthest from mesa)	Flat	25.000000000	-31.700000000
	FNW2	Flat	25.000000000	-31.700000000
	FNW3	Flat	25.000000000	-31.700000000
	FNW4	Flat	25.000000000	-31.700000000
	FOOTNW (foot slope)	Footslope	25.153018150	-31.638381415
	SLNW3 (Slope lower)	Slope	25.156370362	-31.640207596
	SLNW2 (Slope middel)	Slope	25.160183561	-31.641485175
	SLNW1 (Slope upper)	Slope	25.163091510	-31.642579760
	TSE (Plateau SE)	Plateau	25.168685670	-31.647201000
	TSW (Plateau SW)	Plateau	25.164498330	-31.646621170
	TNW (Plateau NW)	Plateau	25.165063170	-31.643751170
	TNE (Plateau NE)	Plateau	25.168217670	-31.643119170
	TN (Plateau central N)	Plateau	25.166329330	-31.643205000
	TS (Plateau central S)	Plateau	25.166685500	-31.647259500
	SLSE1 (Slope upper)	Slope	25.251716503	-31.648620170
	SLSE2 (Slope middel)	Slope	25.174244500	-31.649798500
	SLSE3 (Slope lower)	Slope	25.176424170	-31.650442830
	FOOTSE (footslope)	Footslope	25.180080000	-31.652989830
	FSE4	Flat	25.183072392	-31.658726560
	FSE3	Flat	25.185154026	-31.660193898
	FSE2	Flat	25.187393590	-31.661910461
	FSE1 (furthest from mesa)	Flat	25.189282591	-31.663860828

Table 2.1(cont): Detailed information for all permanent study sites. Latitude and longitude data are presented in decimal degrees.

Mesa	Site code	Habitat	Longitude	Latitude
	FNE1 (furthest from mesa)	Flat	25.192456043	-31.633288134
	FNE2	Flat	25.189579559	-31.633833130
	FNE3	Flat	25.185678640	-31.634870607
	FNE4	Flat	25.183083720	-31.636055320
	FOOTNE (fooslope)	Footslope	25.182209283	-31.636450492
	SLNE3 (Slope lower)	Slope	25.178887974	-31.638188543
	SLNE2 (Slope middel)	Slope	25.177111060	-31.639345602
	SLNE1 (Slope upper)	Slope	25.174611543	-31.640178788
	FSW1 (furthest from mesa)	Flat	25.152118719	-31.666172733
	FSW2	Flat	25.153390000	-31.664540000
	FSW3	Flat	25.154880000	-31.663080000
	FSW4	Flat	25.152118719	-31.666172733
	FOOTSW (footslope)	Footslope	25.158508798	-31.658137339
	SLSW3 (Slope lower)	Slope	25.160800191	-31.655096738
	SLSW2 (Slope middel)	Slope	25.162578189	-31.653046532
	SLSW1 (Slope upper)	Slope	25.163961887	-31.651571571
Folminskop	FNW1 (furthest from mesa)	Flat	25.128515805	-31.553296331
	FNW2	Flat	25.130121515	-31.554828584
	FNW3	Flat	25.313665597	-31.556745177
	FNW4	Flat	25.133795798	-31.558337562
	SLNW2 (Slope lower)	Slope	25.136180000	-31.560920000
	SLNW1 (Slope upper)	Slope	25.137455793	-31.561765337
	TSE (Plateau SE)	Plateau	25.140168908	-31.565624464
	TNW (Plateau NW)	Plateau	25.138231586	-31.563272750
	TN (Plateau central N)	Plateau	25.139440855	-31.563800187
	SLSE1 (Slope upper)	Slope	25.141054372	-31.566474126
	SLSE2 (Slope lower)	Slope	25.143161758	-31.566944047
	FSE4	Flat	25.145380588	-31.569065667
	FSE3	Flat	25.146720640	-31.570885827
	FSE2	Flat	25.148159280	-31.572994341
	FSE1 (furthest from mesa)	Flat	25.150302750	-31.574436864
	FNE1 (furthest from mesa)	Flat	25.144397379	-31.559516836
	FNE2	Flat	25.146337454	-31.557922098
	FNE3	Flat	25.147671852	-31.555906881
	SLNE2 (Slope lower)	Slope	25.142501046	-31.561114031
	SLNE1 (Slope upper)	Slope	25.141483423	-31.561793374
	FSW1 (furthest from mesa)	Flat	25.128364649	-31.573637324
	FSW2	Flat	25.130260781	-31.577992702
	FSW3	Flat	25.131593219	-31.570249959
	FSW4	Flat	25.134298012	-31.569149405
	SLSW2 (Slope lower)	Slope	25.136144500	-31.567530170

Table 2.1(cont): Detailed information for all permanent study sites. Latitude and longitude data are presented in decimal degrees.

Mesa	Site code	Habitat	Longitude	Latitude
	SLSW1 (Slope upper)	Slope	25.137489830	-31.566516830
Buffelskop	FNW1 (furthest from mesa)	Flat	25.107511836	-31.522757959
	FNW2	Flat	25.109367422	-31.523705988
	FNW3	Flat	25.111496106	-31.524812421
	FNW4	Flat	25.113513356	-31.526109336
	SLNW2 (Slope lower)	Slope	25.115905447	-31.527811374
	SLNW1 (Slope upper)	Slope	25.116207494	-31.528338098
	TSE (Plateau SE)	Plateau	25.117742533	-31.530691119
	TNW (Plateau NW)	Plateau	25.000000000	-31.500000000
	SLSE1 (Slope upper)	Slope	25.000000000	-31.500000000
	SLSE2 (Slope lower)	Slope	25.000000000	-31.500000000
	FSE4	Flat	25.123287094	-31.532483359
	FSE3	Flat	25.125244030	-31.533737360
	FSE2	Flat	25.126846000	-31.535304000
	FSE1 (furthest from mesa)	Flat	25.128592000	-31.537076170
	FNE1 (furthest from mesa)	Flat	25.122967977	-31.519748094
	FNE2	Flat	25.121951881	-31.521724834
	FNE3	Flat	25.121038019	-31.523668980
	FNE4	Flat	25.120303124	-31.525481331
	SLNE2 (Slope lower)	Slope	25.100000000	-31.500000000
	SLNE1 (Slope upper)	Slope	25.100000000	-31.500000000
	FSW1 (furthest from mesa)	Flat	25.110794191	-31.536626219
	FSW2	Flat	25.111572320	-31.535682264
	FSW3	Flat	25.113479480	-31.534334898
	SLSW2 (Slope lower)	Slope	25.100000000	-31.500000000
	SLSW1 (Slope upper)	Slope	25.117071129	-31.532421385

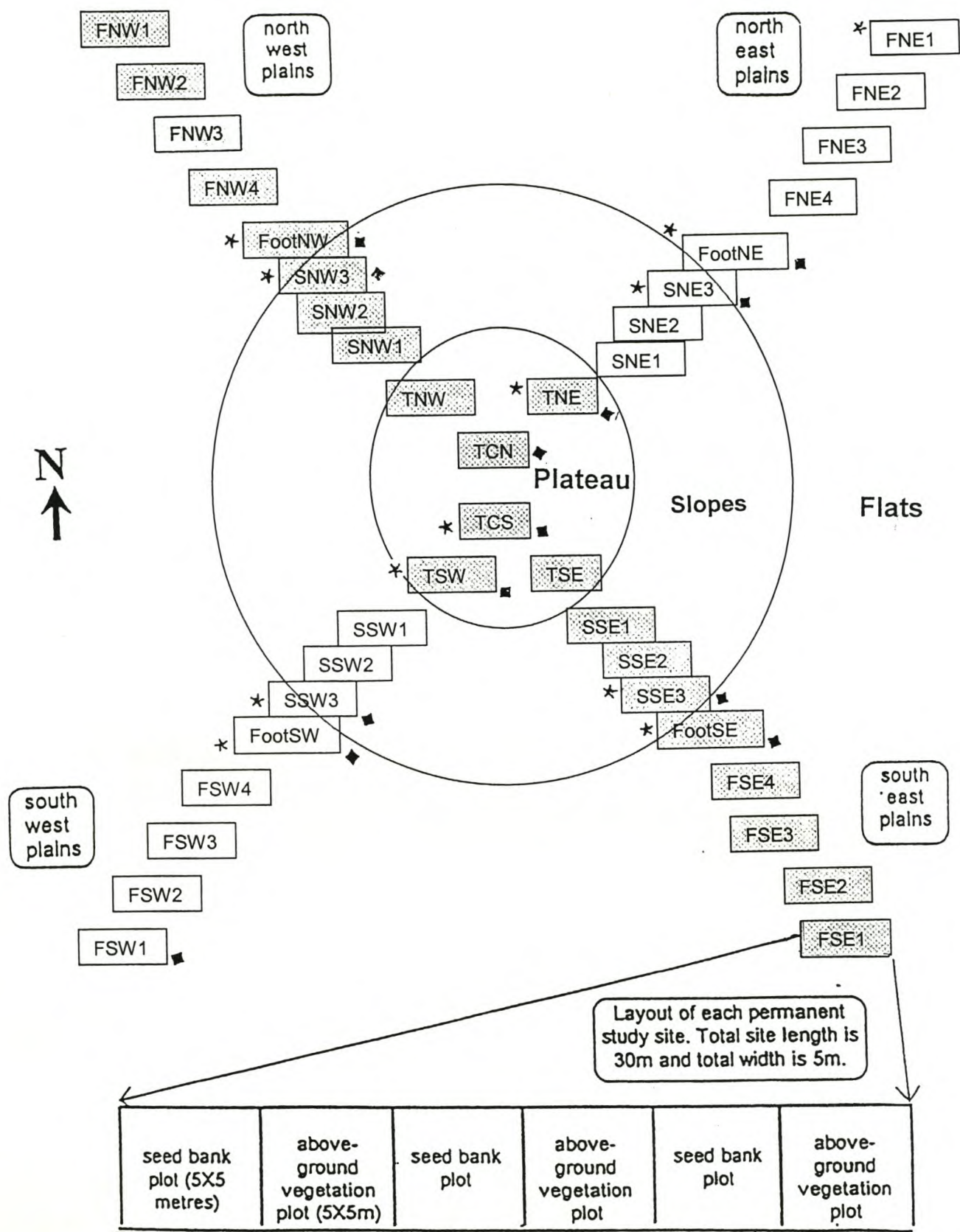


Figure 2.4: Schematic representation of position and layout of permanent study sites on- and off- mesas. * = Indicates sites that were not sampled for dung pellet density and soil on Fominkskop; ♦ = indicates sites that were not sampled for dung pellet density and soil on Buffelskop. Shaded sites represent those that were sampled for dung seed germination study on Tafelberg mesa.

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Chapter 3: Dung pellets and surrogates of soil physical properties can be used as indicators of differential abundance and impact of herbivores on landscapes in the Nama-Karoo Biome of the Middelburg District.**3.1 Abstract**

Domestic livestock, in particular sheep, are used extensively for rangeland farming in the Middelburg District, Eastern Cape. It was hypothesized that habitat use by grazers would be less concentrated on the plateaux of mesas compared to the surrounding flats. To address this hypothesis, this chapter investigates if differential dung pellet abundance can be used as a possible indicator of habitat use by grazers and be subsequently correlated with bare soil patchiness, trampling impact and percentage litter cover at different parts of the landscape in order to detect habitat degradation. When all the dung pellet data were combined over the three mesas to reflect habitat use, overall high mean dung pellet abundance on the plateaux (53 dung pellets.m⁻²) was recorded for the study area. This suggests that habitat use by grazers was not less concentrated on the plateau of mesas compared to the slopes (55 dung pellets.m⁻²) or surrounding flats (34 dung pellets.m⁻²). The Tafelberg mesa was the only study site that was consistent with this hypothesis, whilst the high mean dung pellet density on the plateaux of the smaller Folminkskop and Buffelskop mesas due to easier access contradicted the original hypothesis. Trampling impact was a poor indicator of habitat use, as methods used did not differentiate enough between heavy trampling and evidence of trampling for indicating patterns in habitat use. However, this study showed that bare soil patches and percent litter cover could be used as possible indicators of habitat use and degradation of the different parts of the landscape. It would appear that low-lying altitudinal habitats in the Middelburg District are more susceptible to degradation than higher lying areas and until management actions are considered, these areas are potentially prone to further degradation.

3.2 Introduction

Livestock, such as sheep and to lesser extent cattle, are used extensively for rangeland farming in the Nama-Karoo Biome. These animals can cause disproportionate damage to the veld, as well as competing with indigenous animals for scarce food resources

(Vetter 1998). According to Stokes (1994), domestic animals are contributing to the deterioration of rangeland condition, which leads to the progressive elimination of the most utilized plant species. Livestock are capable of consuming up to 75% of the primary productivity (Noy-Meir 1974) and the effects of overgrazing are particularly severe in arid and semi-arid ecosystems because of environmental stress factors, which limit vegetative and reproductive growth (Roux and Vorster 1983; van der Heyden 1992). Desertification of arid and semi-arid areas has become a worldwide threat (Whitford 1997), and the result of overgrazing is commonly considered to be the most important cause of vegetation change and desertification of the Karoo (Dyer and Tyson 1977). Vegetation change is also caused by high rates of soil loss (Roux and Opperman 1982) and climatic changes (Roux 1981). It is being argued that present day rainfall also leads to vegetation change by causing moisture stresses leading to drought (Roux 1981). Remote sensing studies by Hanan *et al.* (1991) suggest that climatic variability is a major factor of vegetation change.

Because domestic stock and indigenous animals are so widely distributed over the Nama-Karoo landscape, it is important to understand how the animals interact with topography for grazing. For some livestock, the plateaux of mesas might be inaccessible due to steep topography or a lack of water (Defosse *et al.* 1997) or simply because farmers have “fenced” it off. The high cliffs above most of the upper slopes of the dolerite-capped Tafelberg and Folminkskop mesas serve as barriers to prevent access to the plateau. The only points of access to the plateau are several small ravines whilst the rest of both plateaux and slopes are rocky and littered with unstable surface rock rubble. Access to the summit of smaller mesas is possible because of less steep slopes and hardly any plateau, for example the Buffelskop mesa. A lack of access to plateaux, especially Tafelberg mesa, by livestock might result in grazing gradients and overall vegetation changes. For example, one would expect an increase in species diversity as one move from a heavily grazed area through to a moderately grazed area (Barker *et al.* 1989).

Not all grazing, however, is considered to be bad since grasslands have co-evolved with grazers. In the absence of grazers, decreasing species richness can also occur (McNaughton 1979; McNaughton 1984). Wallace *et al.* (1984) reported that grass species from heavily grazed grasslands of the Serengeti ecosystems in Tanzania are

good examples of species that have long co-evolved with grazers and are most likely to be mutualistically associated with them.

This study does not directly test for dung pellet distribution as a surrogate for animal distribution in the landscape since actual animal numbers were never considered. In the absence of direct observations, the aim of this study was to test the differential abundance and impact of animals on different parts of the landscape. As such, dung pellet density in this study were correlated with surrogates of soil physical properties including bare soil, trampling and litter cover as indicators of habitat use and degradation in the Middelburg District of the Eastern Cape.

3.3 Methods

Permanent study sites were located on the plateaux, slopes and flats off and around three mesas in the Middelburg District of the Eastern Cape. A total of eighty-nine permanent study sites were sampled (See Chapter 2). Notably, both the plateaux of the Tafelberg and Folminkskop mesas were fenced off beneath the high cliffs. No such fence existed on Buffelskop, implying therefore that both livestock and indigenous animals had access to this plateau.

3.3.1 Data collection

Dung pellet density were used to assess habitat use of grazing animals across the landscape. In the absence of direct observations in this study, I wished to test the different abundances and impacts of animals on different parts of the landscape. Data were collected in May to June 1999 from sites on- and off- Tafelberg, September to October 1999 for sites on- and off- Folminkskop and during November 1999 for sites on- and off- Buffelskop. The remainder of the sampling was completed during May 2000 for sites (SE slopes and NE flats) at Buffelskop. At each site, a variety of variables were measured including: 1) dung pellet density, 2) trampling impact assessment, 3) bare soil estimates and 4) litter cover content.

3.3.1.1) *Habitat use by grazing animals*

At each permanent study site, three vegetation plots were sampled for dung pellet density. Within these plots, three 1x1 m quadrates were randomly placed out and used as three replicates from which the average dung pellet counts per plot were calculated.

In order to differentiate between recent and past animal presence, dung pellets were further classified according to age (Vetter 1996). Scores were allocated to dung pellets in each quadrat as follows: gray dung pellets were considered old and given a score of 1 (old); dung pellets that retained their shape but were dry and dark in color were given a score of 2 (intermediate); fresh dung pellets, identified by its fresh soft texture, were scored 3 (recent). Quadrats without dung pellets were awarded a score of zero. Dung pellets were not differentiated between domestic and indigenous animals due to identification difficulties. While this may influence the assessment of habitat use, it was assumed that general differences in terms of grazing intensities would still be observed.

3.3.1.2) *Trampling impact*

Trampling impact assessment within each quadrat was based on subjective ranking according to the following scores: (1) evidence of trampling (e.g. low animal hoof activity); (2) moderate trampling (e.g. hoof activity that damaged soil surface) and (3) heavy trampling (hoof activity that damaged soil surface and plants). A score of zero was allocated where no trampling was observed.

3.3.1.3) *Bare soil estimation*

A percentage cover estimate was allocated to bare soil (areas where no plant and rock cover was present) by visual estimation for each quadrat.

3.3.1.4) *Litter cover*

A percentage estimate was assigned for the total litter cover (detached leaves, stems, twigs, dung pellet, etc.) by visual estimation for each quadrat.

3.3.2 Data analysis

A combination of descriptive statistical analysis consisting of means; percentages; correlations and standard deviations were used to describe and analyze data. Analysis of variance (ANOVA) was performed to identify trends in differential dung pellet abundance, bare soil percentages, litter cover percentages related to the different parts of the landscape (STATISTICA 1999). Data was stored in Arcview (ESRI) format which was downloaded as ArcView shape files, a computer program called MapInfo professional version 5.5 (MapInfo Corporation 1999) was used to translate into tab format files to display the variation in the data using thematic maps with contours.

3.4 Results

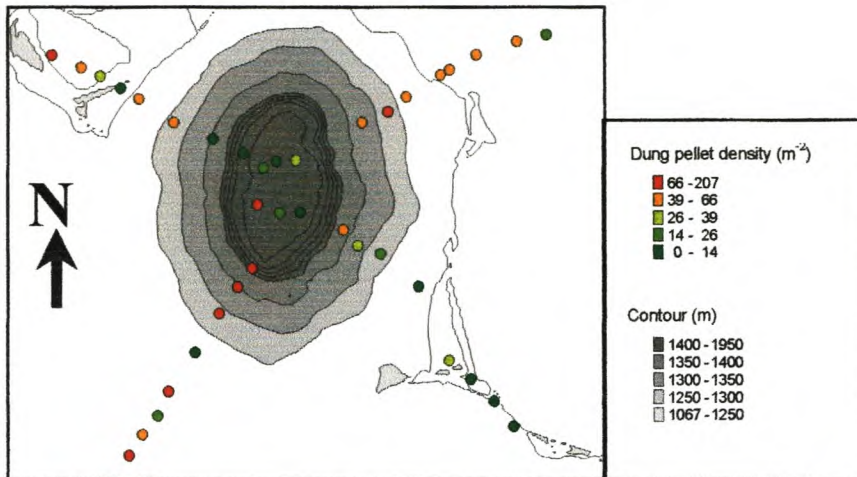
3.4.1) Habitat use by grazing animals

Dung pellets were found on all three mesas. Statistical analyses (ANOVA) showed no significant overall differences in dung pellet density between the three mesas ($p = 0.744$; $df = 2, 86$; $F = 0.3$) (Table 3.1). The mean dung pellet density on the plateau of Folminkskop was about two times greater than that on the Buffelskop plateau and three times greater than that on Tafelberg plateau, but differences were not statistically different ($p = 0.218$; $df = 2, 8$; $F = 1.9$). The flats of all three mesas also showed no significant differences with respect to dung pellet density ($p = 0.079$; $df = 2, 39$; $F = 2.69$).

There was variation in dung pellet density for the different habitats of the mesas ($p < 0.05$; $df = 2, 86$; $F = 3.26$) (Table 3.1). Overall, flats (34 dung pellets.m⁻²) had the least mean dung pellet density per study site compared to the higher dung pellet density on slopes (55 dung pellets.m⁻²) and plateaux (53 dung pellets.m⁻²). There was a clear indication that the flats and slopes of the Tafelberg mesa were used for livestock grazing according to the dung pellet density. High dung pellet densities were recorded on the slopes and plateaux of Folminkskop and Buffelskop. In particular, the northeastern and southwestern proportions (including slopes and flats) of the Tafelberg mesa had higher dung pellet densities than those recorded in any other research study site. Sites on the plateau and southeastern slopes of Folminkskop had also higher dung pellet densities when compared to the sites on the plateau of Tafelberg mesa (Figure 3.1a and b).

Based on the relationship between dung pellet density and age, no single habitat was significantly more utilized than another habitat regardless of the mesa ($p = 0.07$; $df = 2, 86$; $F = 2.8$) (Table 3.2). In most cases, dung pellets of either an intermediate or fresh age was recorded at all the study sites, implying relatively recent habitat use for all sites.

a) Tafelberg



b) Folminkskop

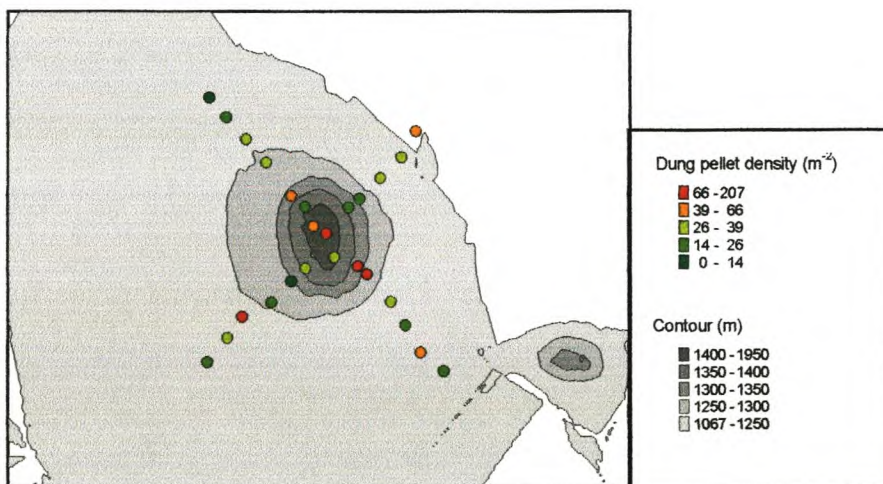


Figure 3.1: Distribution of dung pellet density classes in relation to the three mesas and their surroundings (a= Tafelberg; b= Folminkskop). Circles represent the position and layout of permanent sites on- and off- mesas, located on four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean density of dung pellet recorded (refer to legend). Dung pellet density refers to the number of dung pellets counted (m^{-2})

c) Buffelskop

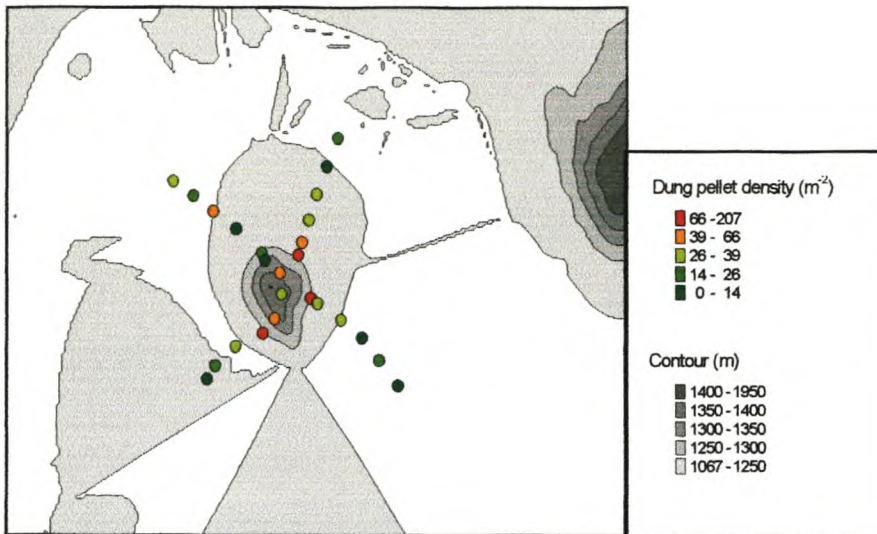


Figure 3.1 (cont): Distribution of dung pellet density classes in relation to the three mesas and their surroundings (c= Buffelskop). Circles represent the position and layout of permanent sites on- and off- mesas, located on four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean density of dung pellet recorded (refer to legend). Dung pellet density refers to the number of dung pellets counted (m^{-2}).

Table 3.1: Means \pm standard error for dung pellet density at different mesas with respect to their different habitats. Sample size (n) is the number of study sites that were sampled. Total refers to combined habitat data.

Mesas	Habitat	Dung pellet density (m^{-2})	Total	Sample size (n)
Tafelberg	flat	45.2 \pm 9.9	44.5 \pm 5.9	16
	slope	49.3 \pm 8.9		16
	plateau	29.7 \pm 12.8		6
Folminkskop	flat	32.2 \pm 4.4	46.9 \pm 8.8	15
	slope	54.2 \pm 17.1		8
	plateau	101.4 \pm 52.9		3
Buffelskop	flat	32.3 \pm 3.7	38.8 \pm 7.2	15
	slope	65.4 \pm 18.11		8
	plateau	49.2 \pm 16.29		2

Table 3.2: Means \pm standard error of dung pellet density for different dung pellet age classes (old; intermediate and fresh) with respect to their habitats for all three mesas.

Mesas ↓	Habitat ↓	Dung pellet density (m ⁻²)		
		Old	Intermediate	Fresh
Tafelberg	flat	0.7 \pm 0	40.7 \pm 8.9	96.9 \pm 7.6
	slope	0	54.1 \pm 7.5	97.8 \pm 11.1
	plateau	13.2 \pm 2.8	37.9 \pm 15.4	128.4 \pm 0
Folminkskop	flat	0	32.2 \pm 4.4	0
	slope	0	43.6 \pm 14.6	128.4 \pm 0
	plateau	0	101 \pm 53.9	0
Buffelskop	flat	4.4 \pm 0	21.7 \pm 2.9	42 \pm 5.6
	slope	0	32.9 \pm 8.7	97.9 \pm 18.6
	plateau	0	65.4 \pm 0	33 \pm 0

3.4.2) Trampling impact

There was evidence of trampling impact on all the different habitats for all three mesas. The slopes of the Folminkskop mesa were the only exception where no trampling was observed. Trampling impact scores were significantly correlated with dung pellet density (Spearman $R = 0.602$; $n = 89$; $p < 0.001$).

Table 3.3: Means \pm standard error for trampling impact at different habitats of all mesas. Mean value 1 indicates evidence of trampling impact, while mean value 0 indicates no trampling impact. Sample size (n) indicates the number of sampling sites at different habitats for the different mesas.

Mesas	Habitat	Trampling class	Sample size (n)
Tafelberg	flat	1 \pm 0.18	16
	slope	1 \pm 0.10	16
	plateau	1 \pm 0.11	6
Folminkskop	flat	1 \pm 0.08	15
	slope	0 \pm 0.10	8
	plateau	1 \pm 0.23	3
Buffelskop	flat	1 \pm 0.10	15
	slope	1 \pm 0.17	8
	plateau	1 \pm 0.00	2

3.4.3) Bare soil estimation

Figure 3.2 and table 3.4 present the percentage bare soil found on the different habitats for all three mesas. A highly significant difference ($p < 0.001$; $df = 2, 86$; $F = 58.3$) was found for bare soil when the different habitats were compared across the three mesas. It clearly showed that more bare patches (ranging between 48 to 76 % per study site) were found on the flats surrounding the mesas. A highly significant difference of bare soil was also found on the plateaux of all three mesas ($p < 0.001$; $df = 2, 8$; $F = 30.94$). The small plateau of the Buffelskop mesa had the highest percent of bare soil (19.2 %) compared to that on Tafelberg (5 %). The plateaux of the Folminkskop and Buffelskop mesas showed no significant difference in percentage bare soil ($p = 0.866$; $df = 1, 3$; $F = 0.034$). A Pearsons Product- Moment correlation showed a significant correlation between bare soil and dung pellet density ($r = 0.02$; $n = 89$; $p < 0.05$).

a) Tafelberg

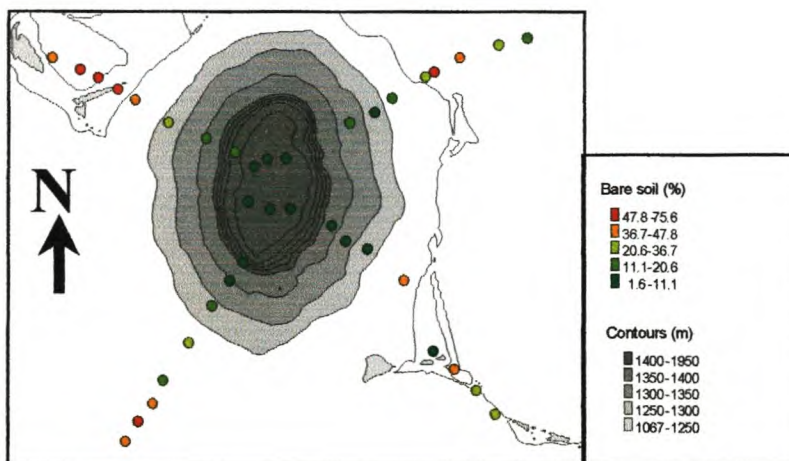
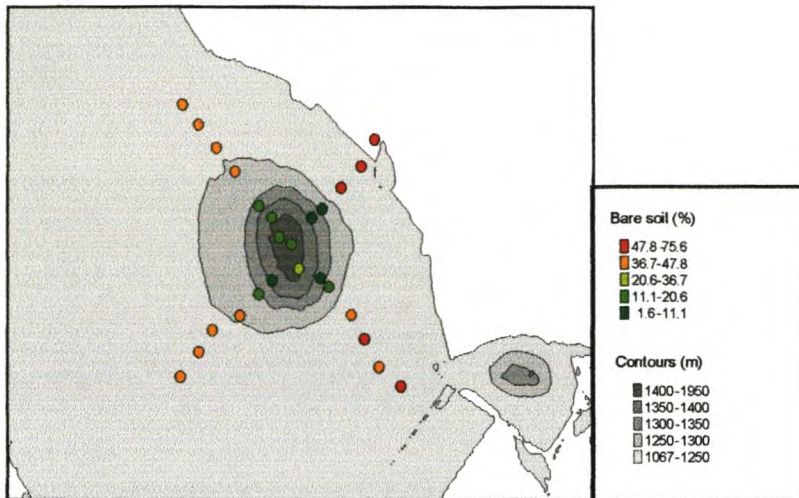


Figure 3.2: Distribution of (%) bare soil in relation to the three mesas and their surroundings (a= Tafelberg). Circles represent the position and layout of permanent sites on- and off- mesas, located at four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean percentage of bare soil (%) recorded (refer to legend).

b) Folminkskop



c) Buffelskop

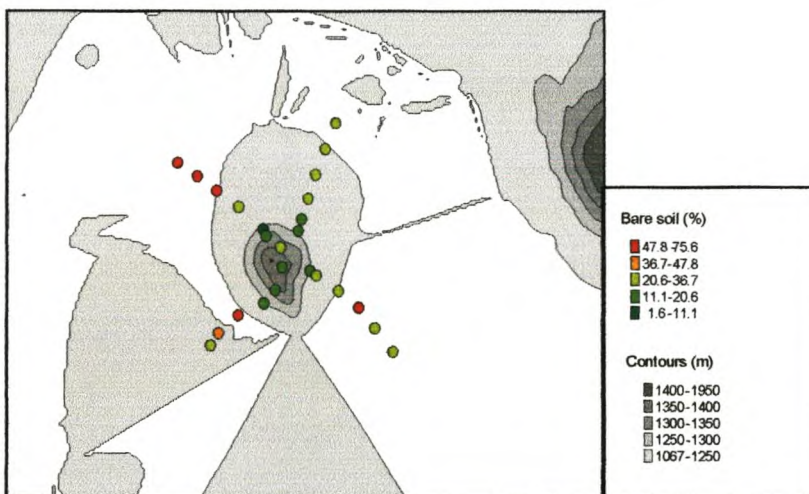


Figure 3.2: Distribution of (%) bare soil in relation to the three mesas and their surroundings (b= Folminkskop; c= Buffelskop). Circles represent the position and layout of permanent sites on- and off- mesas, located at four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean percentage of bare soil (%) recorded (refer to legend).

Table 3.4: Means \pm standard error for percentage bare soil and percentage litter cover for the different habitats of the mesas. Sample size (n) indicates the number of sample sites for different habitats for the different mesas.

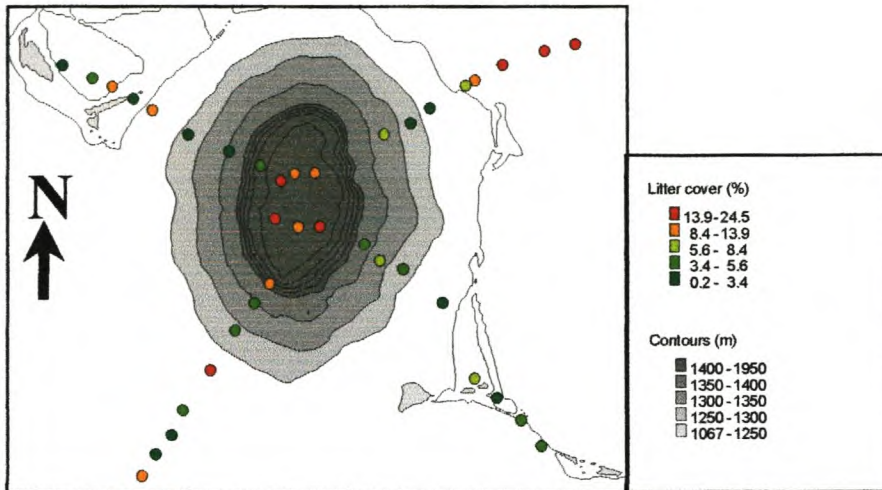
Mesas	Habitat	Bare soil (%)	Litter cover (%)	Sample size (n)
Tafelberg	flat	41.5 \pm 4.6	7.8 \pm 1.7	16
	slope	17.5 \pm 3.2	5.6 \pm 1.0	16
	plateau	5 \pm 0.9	13.9 \pm 1.2	6
Folminkskop	flat	51.4 \pm 3.4	5.7 \pm 0.9	15
	slope	11.1 \pm 1.4	8.3 \pm 2.0	8
	plateau	18.5 \pm 2.3	12.6 \pm 1.0	3
Buffelskop	flat	43.5 \pm 4.5	9.8 \pm 1.9	15
	slope	16.9 \pm 1.5	6.8 \pm 0.7	8
	plateau	19.2 \pm 2.5	10.1 \pm 0.1	2

3.4.4) Litter cover

Figure 3.3 show the variation in percentage litter cover per study site found at different habitats for the three mesas, whilst Table 3.4 displays the mean percentage litter cover for the different habitats. No significant differences were found for overall litter cover between mesas ($p = 0.576$; $df = 2, 86$; $F = 0.55$).

The percentage litter cover, however, for the different habitats was highly significant ($p < 0.01$; $df = 2, 86$; $F = 5.97$). A higher percentage litter cover was recorded for the plateaux of all the three mesas compared to slopes and flats. Study sites with the least percentage litter cover were found on the flats, ranging from 0.2 % to 3.4 % per study site. The percentage litter cover was significantly correlation with the percent bare soil ($r = 0.02$; $n = 89$; $p < 0.05$). Percentage litter cover did not correlate with dung pellet density per study site ($r = 0.104$; $n = 89$; $p = 0.334$).

a) Tafelberg



b) Folminkskop

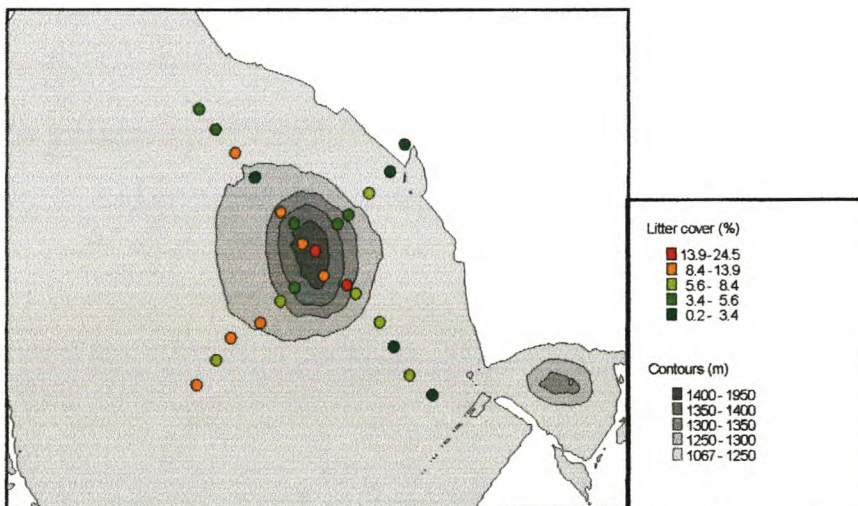


Figure 3.3 Distribution of litter cover (%) in relation to the three mesas and their surroundings (a= Tafelberg; b= Folminkskop). Circles represent the position and layout of permanent sites on- and off- mesas, located at four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean density of litter cover (%) recorded (refer to legend).

c) Buffelskop

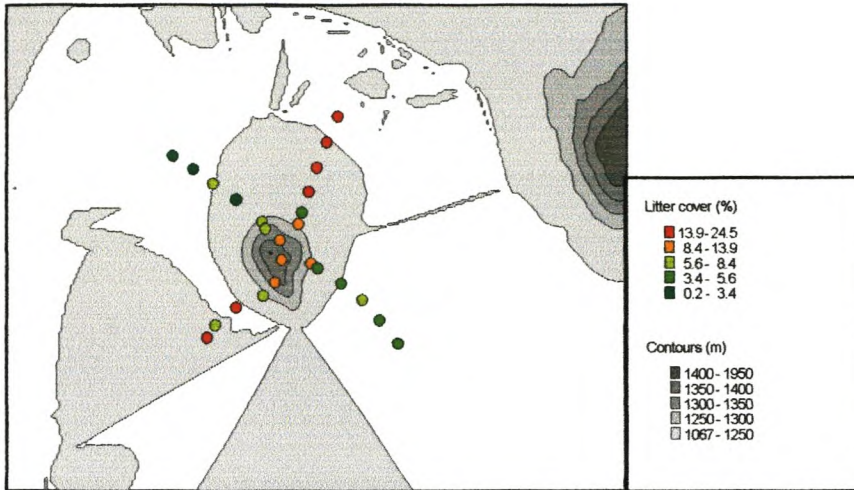


Figure 3.3 (cont): Distribution of litter cover (%) in relation to the three mesas and their surroundings (c= Buffelskop). Circles represent the position and layout of permanent sites on- and off- mesas, located at four compass half- points (NW; SW; NE and SE). The colour at each permanent study site represents the mean density of litter cover (%) recorded (refer to legend).

3.5 Discussion

In the past, several research studies have used dung pellet density as an indicator of patterns of habitat use by animals (Leopold *et al.* 1984; Vetter 1996). The assumption in this thesis is that dung counts can be used as a surrogate for animal counts, an assumption not tested in this study. When combining data, the overall dung pellet density for flats, slopes and plateaux did not show a clear pattern. This suggests, if the assumption is legitimate, that there is no clear difference in the differential abundance and impact of animals between main habitats in the landscape. However, the data for Tafelberg mesa alone provided evidence of significantly lower dung pellet abundance on the plateau. This was the only mesa of the three studied that conformed to the hypothesis that mesas, with less accessibility are in essence “conservation islands”, protected from grazing.

A significant difference in dung pellet densities located at different habitats can be associated with concentration of feeding activity during the day (Ellis *et al.* 1998). A study done in New South Wales (Johnson *et al.* 1987) showed that animals rarely defecated while they rested during the day, but increased their dung pellet production during their first hour after rising and beginning to feed. The flats of all three mesas were equally accessible to livestock and herbivores. In the case of the smaller mesas, livestock grazed on the plateaux as well as the flats and slopes. According to Pienaar (2002), definite variation in species composition within plant communities occurred between the flats and plateaux of all three mesas. The plant communities occurring at these habitats were distinctly different from each other. No plant communities were shared between the flats and plateaux of mesas (Pienaar 2002). Therefore, differences in habitat use may be due to preferences of grazing in certain communities or to physical factors such as steep slopes, which prevent movement of domestic stock or to the fact that farmers tend to camp off habitat types and rotate their stock. There is no one correct answer. The slope degree is of considerable importance in veld management because it affects both vegetation productivity and use by animals. According to Joubert (1997), domestic stock and indigenous animals can move up the slopes until the gradient becomes too steep and unreachable for the animals. Livestock use, particular cattle, decreased with increasing slope because of the difficulty the animals have in climbing (Holechek *et al.* 1995). Grazers clearly moved up the slopes to graze on the plateaux of the smaller mesas (Holechek *et al.* 1995). The ratio of palatable versus unpalatable

plant species may also contribute to the movement of animals up slopes. From personal observations on the case of Tafelberg mesa, livestock are apt to move three quarters up the slopes until they reach several physical barriers, including the fence line that was erected to prevent stock from moving on to the plateau. The reason for the fence, however, was because of the 20 to 40 m high cliffs above most of the upper slopes (Jones 2001) and a lack of water points on the plateau itself. These high cliffs and slopes serve as natural barriers to the use of the plateau. Unlike the smaller Buffelskop mesa where the animals grazed over the entire landscape gradient even reaching the plateau, the plateau of Tafelberg has not been grazed by domestic stock since the last three decades. Small herds of game such as *Tragelaphus strepsiceros* (Kudu) and *Pelea capreolus* (Rhebuck), however, regularly graze the slopes of Tafelberg. The plateau is utilized by smaller herbivores such as *Procavia capensis* (Rock Dassie), *Pronolagus rupestris* (Red Rock Rabbit) etc.

It is suggested that the differential abundance in dung pellets and impacts of animals on different parts of the landscape (long-term indicators) correlated, and are related to differences in grazing pressure. Evidence for this suggestion stems from a significant correlation between dung pellet density and bare soil. According to Bosch and Kellner (1991), a reduction in plant cover due to grazing animals can lead to an increase in patchiness (i.e. patches of exposed soil). Bare patches can be used as a good predictor of degradation (Walters 1951). Bare patches can usually be found around areas where ground is trampled by grazers due to their hoof action, and were most common on the flats surrounding the three mesas. The correlation between bare soil and dung pellet density can arguably be associated that bare soil has been linked to degradation and that dung pellet density is correlated with bare soil, therefore degradation on flat areas can be attributed to high animal concentrations (Vetter 1996). It is suggested that a higher density of emergent rock, a greater diversity and relatively dense plant cover, as well a lower intensity of grazing on the mesa plateaux and slopes ensures that there is less degradation at these sites than on the flats (Jones 2000). In the case of this study, however, the high percentage bare soil on the plateaux of the Folminkskop and Buffelskop mesas than the plateau of the Tafelberg mesa was due to the fact that these two smaller mesas were used mainly as grazing camps under a rotational scheme (Bull van Heerden, pers com).

Walters (1951) suggested that bare patches in the Karoo would steadily increase in size, and will ultimately cause considerable problems in terms of management. These vegetation changes, due to more grazing pressure, can lead to degradation which in turn leads to soil loss and changes in soil properties. The flats in this research study have been used extensively as rangelands for many decades. Pienaar (2002) suggested that the plant species commonly found on these flats could possibly indicate over-utilization of natural pastures.

The results showed that habitats with a high percentage bare soil have a lower percentage litter cover. According to Kelley and Walker (1975), more bare patches were present in areas that were intensively used for grazing, which means that a very small percentage of the vegetation becomes litter. These intensively used areas remain bare and poorly protected from the sun, rain and wind. The reason for the higher percentage litter found on the plateaux of the three mesas than the slopes and flats could possibly be due to restricted access by livestock to the plateau. The high percentage litter cover at the northeastern study sites of the flats around the Tafelberg mesa (Figure 3.3a), was due to the fact that these sites were excluded from grazing to allow the vegetation to recover (William Asher, pers com). Heavy grazing can cause a reduction in plant cover, which results in less litter cover due to overgrazing (Chambers and Norton 1993). Litter is very important in a healthy vegetation community in terms of nutrient cycling and fertile patches. High occurrences of annual plants are generally associated with high disturbance rates. Annuals that are not grazed and die back are usually associated with high disturbance rates that contribute to the high percentage litter found at different sites within the different habitats for the mesas (Jones 2000).

Restoration programs must be considered to improve bare soil patches and, similarly, to increase overall plant cover and plant species diversity. There is no doubt that topography (mesas) plays an important role in the karoo landscape. This study emphasized that large mesas with steep slopes appear to act as safe havens against very intense grazing. Non-degraded vegetation is characterized by a high abundance of palatable grasses (Bosch and Gauch 1991). *Themeda triandra* was found to be one of the dominant species on the plateau of Tafelberg mesa. This grass species also occurred on the plateaux of Folminkskop and Buffelskop, but to a lesser extent (Pienaar 2002). Bosch and Gauch (1991) also noted that undegraded vegetation was also

characterized by a high abundance of palatable grasses such as *T. triandra*. The mesas therefore act as a refuge for *T. triandra* and other palatable species that can be used as a seed or propagule source for restoration of overgrazed flats. It is evident that mesas are currently somewhat less impacted than surrounding flats, but not all to the same extent, depending primarily on accessibility. However, the rocky nature of the habitats on mesas suggests that it is less inclined to be degraded, even if they are grazed. This makes mesas worthy of conservation.

3.6 Conclusion

The greatest benefit of using dung pellets as indicators of habitat use is that it provides a continuous sampling profile, which is always available to researchers. The fact that dung pellet density did not clearly turn out to be an indicator of habitat use in this study, supports the current debate as to whether it can be used as a parameter of degradation (Ellis and Swift 1988; Tapson 1993; Sullivan 1996). The results showed that where slopes and plateaux were accessible to herbivores, as in the case for the Buffelskop mesa, abundance of dung pellets were found suggesting that higher intensities of habitat use took place. In the case of the inaccessible plateau of the Tafelberg mesa, steeper slopes, high cliffs, and a fenced barrier prevented livestock grazing in these areas. The intercorrelations between differential dung pellet abundance and surrogates of soil physical properties associated with degradation were useful exercises to examine different habitat use by grazers. A short-coming in this study, was that the estimates of trampling impact were not discriminating enough to highlight any patterns in habitat use that made ecological sense. However, the flat areas showed more evidence of degradation when defined in terms of patchiness of bare soil and less litter cover, suggesting that low-lying rangelands are more susceptible to degradation than higher lying areas under the current grazing practices. These degraded systems are potentially prone to further degradation, being more sensitive to natural stresses such as droughts (Hoffman *et al.* 1999). Landowners and managers should view the rangeland conditions as an ingredient for a sustainable and productive future.

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Chapter 4: Analysis of soil chemical composition for different habitats over an altitudinal gradient in the Middelburg District of the Eastern Cape .

4.1 Abstract

This study explored variation in soil macro- and micro-elements between open- and closed-canopy micro-sites at different parts of the landscape with the aim of differentiating between local scales due to land use and landscape scales due to geomorphology. Soil samples were collected from 91 sites on- and off- the Tafelberg, Fominkskop and Buffelskop mesas in the Middelburg District of the Eastern Cape. Soils were analyzed for chemical and physical properties. Results demonstrated that vegetation changes are better explained by landscape scales that include soil properties such as carbon, phosphorus, calcium magnesium, copper and manganese than by grazing effects. This study also found that at the landscape scale, soils from the mesas and their surrounding flats showed significant variation in soil texture. At the local level (i.e. individual plants), however, significant differences in soil were found particularly for potassium, zinc and boron. At this scale, land use may play an important role, as these effects were associated with the presence or absence of plant cover. It is concluded that flats habitats surrounding mesas in the Middelburg District need restoration and the germination of seed found in dung pellets could be a possible technique to restore these degraded areas.

4.2 Introduction

Soil is a living entity in which many of the essential processes that maintain ecosystem integrity are located (Whitford and Herrick 1995). Soils provide habitats for plant species, affecting plant distribution and in turn, plants affect soil characteristics. For example, plant characteristics such as life span, biomass allocation and tissue chemical composition have been shown to have significant effects on ecosystem processes such as nutrient dynamics (Melillo *et al.* 1982; Pastor *et al.* 1984). Therefore, soils in arid and semi-arid regions are an important factor in controlling the abundance and distribution of plants and animals in different part of the landscape (Leonard *et al.* 1988), as has been demonstrated in the Karoo (Lloyd 1989; Palmer *et al.* 1988; Vorster 1986). The crux of this chapter's relevance lies first in whether vegetation changes are better explained by soil or grazing effects, and secondly whether changes in soil have resulted from different land use practices.

Soils of the Karoo are influenced substantially by climate (Jeffrey 1987) and geology (Burke 2002). Rainfall events are key drivers of processes in an arid region such as the Karoo. The Nama-Karoo experiences unpredictable, highly variable and patchy rainfall, resulting in soils that are generally poorly developed, without distinct horizons, except perhaps on depositional plains (Watkeys 1999). The underlying geology and topography has a great influence on the physical and chemical properties of soils (Burke 2002).

In semi-arid regions of South Africa, livestock grazing is considered to be a major cause of land degradation due to inappropriate grazing management strategies which lead to a decline in vegetation cover, followed by soil erosion (Dregne 1990). Soil degradation in South African rangelands is most severe in the Eastern Cape and Northern Cape provinces and the rate of soil degradation is still increasing in these provinces (Hoffman and Ashwell 2001). Degradation is only considered to occur if there is large-scale soil loss (Biot 1993). Soil erosion is regarded as an important problem in South Africa and it occupies a position as one of the indicators of land degradation and desertification (Hoffman and Ashwell 2001; Dahlberg 1996). Soil erosion causes changes in soil composition, and in combination with grazing is a very important factor to consider in rangeland management (Brady 1990). Soil erosion is also affected by the characteristics of soil itself. Debates around rangeland degradation by animals, however, have suggested that climate (especially rainfall) has a greater influence on

vegetation dynamics than pastoral systems in semi-arid areas, and that vegetation has a high capacity to recover from grazing disturbance (Behnke and Scoones 1993; Ellis *et al.* 1993). Hoffman and Ashwell (2001) dispute the latter.

According to Tongway and Hindley (1995), soil forms the fundamental resource for grasslands, and vegetation changes can be associated with changes in soil surface characteristics. If vegetation alone is monitored, it will not give much information as to whether changes in composition are due to interactions between grazing animals and vegetation alone, or whether the soil as a habitat for pasture plants has been degraded. Therefore, soil surface condition provides significant information as to arid grassland status, despite the more rapid condition changes possible within grasslands compared with shrublands. Condition of grasslands can now be assessed not only with respect to composition and cover of the species themselves, but also in terms of the more fundamental and therefore less reversible, changes in the inherent stability of the system, such as soil condition (Tongway and Hindley 1995). This is important, given the need to predict rather than simply describe changes in land condition.

The aim of this study was to determine differences in macro- and micro-elements of soil between open- and closed-canopy sites at different parts of the landscape to differentiate between local scales due to land use and landscape scales due to geomorphology.

4.3 Methods

4.3.1 Soil sampling

Soil was sampled from the permanent study sites on- and off- Tafelberg mesa during May-June 1999, on- and off- Folminkskop mesa during September-October 1999 and on- and off- Buffelskop mesa in November 1999 and again in May 2000 (see Figure 2.4 Chapter 2 for the location of the permanent study sites). Soils were collected from just outside the perimeter (1 meter) of each permanent study site to avoid disturbing the vegetation within the permanent plots. Samples were collected from under the canopies of shrubs (closed-canopy) and from points midway between shrubs in open areas (open-canopy). At every 2.5 meter intervals, approximately 125 mm³ soil samples were taken around a permanent study site. These soil samples were then bulked to give one open- and one closed-canopy sample per site. Soil samples were then air dried before being

sent to the Soil Analysis laboratories at Elsenburg (Department of Agriculture). The samples were analyzed for pH, organic matter content, macro (Carbon %; Phosphorus mg/kg; Potassium mg/kg; Calcium me% Magnesium mg/kg; Copper mg/kg) -and micro (Zinc mg/kg; Manganese mg/kg; Boron mg/kg) nutrient levels, as well as for texture (clay/loam/sand).

4.3.2 Soil condition assessment

The assessment of soil condition, using the Tongway (1995) method, was done only on- and off- Tafelberg mesa. Each site at different parts of the Tafelberg mesa was classified according to its landform and soil surface condition. Within each of the three permanent vegetation plots (5x5 meter) at each site, a sub-plot of 2x2 meter was randomly located.

The following soil condition indicators were examined;

4.3.2.1) *Soil texture*

Four soil textures were identified: (1) silty clay to heavy clay (very slow infiltration rate); (2) sandy clay loam to sandy clay (slow infiltration rate); (3) sandy loam to silt loam (moderate infiltration rate) and (4) sandy to clayey sand (high infiltration rate).

4.3.2.2) *Soil cover*

Soil cover is the projected percentage plant cover of soil. The aim was to assess the degree to which surface and projected plant cover resist rain splash erosion (Tongway 1995). Rocks were also included because it would intercept raindrops and protect the soil from rain splash erosion. Projected plant cover was divided into five classes: very low (< 1%); low (1-15%); high (15-30%) and very high (>50%).

4.3.2.3) *Litter cover*

Litter cover influences the availability of detached organic materials for decomposition and nutrient cycling. The assessment of litter cover was divided into two categories: "local" (i.e. accumulates and decomposes where it falls) and "transported" (mobile). The decomposition potential of litter was further divided into three readily recognizable forms (characterized by the degree of incorporation in the soil); (a) nil incorporation (loosely strewn on surface), (b) moderate incorporation (in intimate contact with surface), and (c) extensive incorporation (partially or wholly covered with soil). Litter was assessed into

six cover classes: 1 (<10%); 2 (10-25%); 3 (25-50%); 4 (50- 75%); 5 (75-100%) and 6 (100%).

4. 3.2.4) *Cryptogam cover*

Cryptogams (i.e. algae, fungi, lichens, mosses and liverworts) are plants that can stabilize and protect the soil surface. Cryptogam cover was assessed into four classes: 1 represents very slight (<1%); 2 represents slight (1-10%); 3 represents moderate (10-50%) and 4 represents extensive (>50%).

4. 3.2.5) *Soil crust integrity*

Soil crust integrity was used to assess to what degree surface crust materials were broken or loosely attached and available for erosion. Crust integrity was divided into four categories or classes: 1 (extensively broken); 2 (moderately broken); 3 (slightly broken); and 4 (still intact).

4. 3.2.6) *Soil erosion features*

Erosion features were used to assess how the surface soil responds to the erosive forces of wind and water. Erosion features include; 1 (extensive), 2 (moderate), 3 (slight) and 4 (insignificant).

4. 3.2.7) *Deposited materials*

This feature was used to assess to what degree-transported materials were deposited in the plots. Deposited materials included sand (0-2 mm); gravel (2-10 mm) and rock (>10 mm). Litter was not included. The eroded materials were divided into four classes: 1 represents extensive (>50%); 2 represents moderate (20-50%); 3 represents slight (5-20%) and 4 represents very slight (0-5%).

4. 3.2.8) *Soil microtopography*

The objective was to assess soil surface "roughness", in the form of surface water retention capacity. Five classes of soil surfaces were investigated, which retain water. Classes include: 1 = smooth and insignificant retention (<3 mm), 2 = a shallow depression with a low retention (3-8 mm), 3 = deeper depressions with moderate retention, includes litter and sediments (8-25 mm), 4 = deep formations, but with visible

base (25-100 mm) while 5 includes very deep formations and extensive features (>100 mm).

4. 3.2.9) *Soil surface nature*

This test was used to assess the likely impact of mechanical stress (e.g. trampling), to yield erodible material. This test is only relevant when the soil crust is dry. The features assessed were crust flexibility and hardness, and divided into five classes; (5) shows some flexibility when pressed with pen or finger pressure, also when surface was a self-mulching clay; (4) crust very hard (need metal tool to break surface); (3) crust moderately hard; (2) crust easily broken with finger pressure while 1 indicates that the surface was loose-sandy.

4. 3.2.10) *Slake test*

The objective was to test for soil stability during rain. A beaker of rainwater was used to see how long the fragments take before they collapse when the surface crust was put into a beaker of water. Four classes were allocated: 1 represents very unstable soil (fragments collapses <5%); 2 represents unstable soil (fragments substantially collapsed over 5-10 seconds, but more than 50% of the sub-crust material slumped to an amorphous mass); 3 represents moderately unstable soil (surface crust remains intact, some slumping of sub-crust material, but <50%) and 4 represents stable soil (fragments remain intact after 5 minutes).

4.3.3 Soil condition calculations

4.3.3.1 *Stability*

The following indicators were used to calculate soil stability: crust integrity (scale 1-4); surface nature (scale 1-4); slake test (scale 1-4); erosion features (scale 1-4); deposited materials (scale 1-4); cryptogam cover (scale 1-4); soil cover (scale 1-6) and litter cover (scale 1-6) (Tongway and Hindley 1995).

The following is a worked example of how soil stability is calculated;

FEATURES	RATING
Soil cover	2 out of 6
Litter cover	1 out of 6
Cryptogam cover	1 out of 4
Crust integrity	3 out of 4
Erosion features	3 out of 4
Deposited material	4 out of 4
Microtopography	2 out of 5

Calculation: $\frac{\text{Cover value}}{\text{Scale}} \times 100 = \%$

Example: $\frac{14}{24} \times 100 = 58\%$

where Cover value refers to the values out of 4 or 6 of each feature and is then added.

and

Scale: if all indicators were present, scale would be 36 but only six indicators were present, therefore scale was 24.

4.3.3.2 Infiltration

The indicators required to calculate soil infiltration include: micro topography (scale 1-5); surface nature (scale 1-4) and litter cover (scale 1-6).

Calculation: $\frac{\text{Cover value}}{\text{Scale}} \times 100 = \%$

where Cover value: refers to the values out of 4, 5 or 6 of each feature and is then added.

and

Scale: if all features were present, scale would be 15.

4.3.3.3 Nutrient status and Cycling

The calculation of nutrient status and cycling requires the following indicators: litter cover, origin and incorporation (scale 1-18); cryptogam cover (scale 1-4) and micro topography (scale 1-5). The full contribution of litter to nutrient status and cycling was obtained by multiplying the basic litter cover by the following factors:

- both transported (T) and nil (N) incorporation of litter, multiply cover value by 1

- b) both litter of local (L) origin and litter with slight (S) incorporation, multiply cover value by 1.5.
- c) for extensive (S) incorporation of litter, multiply the cover value by 2.

Calculation: $\frac{\text{Cover value}}{\text{Scale}} \times 100 = \%$

where Cover value: refers to the values out of 4, 5 or 18 of each feature and is then added.

and

Scale: if all features were present, scale would be 27.

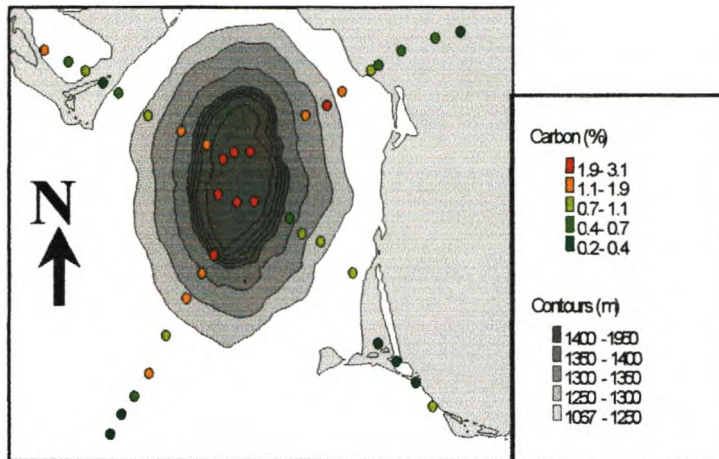
4.4 Results

Table 4.1 is a summary of the soil chemical properties for the macro-elements found in the micro-sites, open- and closed-canopy cover, for the different habitats (flats, slopes plateaux), of the Tafelberg, Folminkskop and Buffelskop mesas.

4.4.1 Variation in soil carbon content

Soil carbon content was significantly different between habitats (flats, slopes and plateaux) of all three mesas ($p < 0.001$; $df = 1, 153$; $F = 5.5$) (Figure 4.1). Higher percentage carbon levels were recorded on the plateaux of the mesas compared to the slopes and flats. There was also a significant difference in percentage carbon content between open- and closed-canopy cover ($p < 0.05$; $df = 1, 153$; $F = 14.1$). Soils from closed-canopy samples contained a higher percentage carbon content (Figure 4.1b, d and f) than those from open-canopy samples (Figure 4.1a, c and e).

a) Tafelberg- open canopy



b) Tafelberg- closed canopy

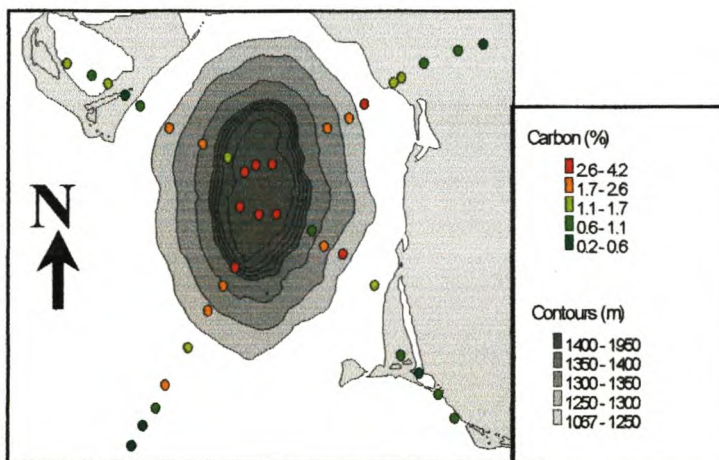
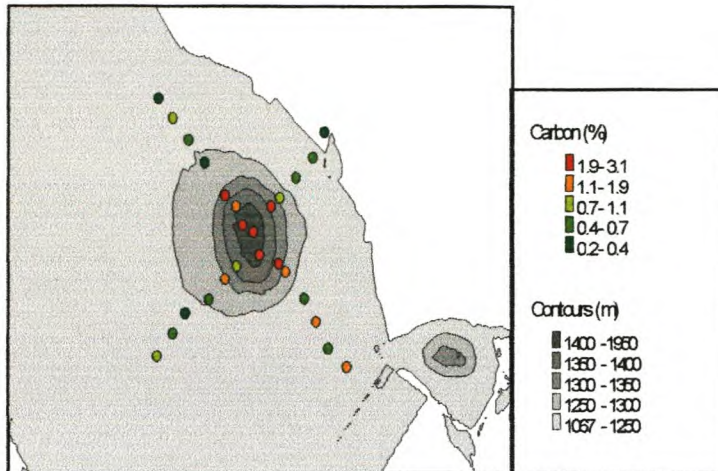


Figure 4.1: Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil carbon content (%) of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil carbon content of closed-canopy samples from flats, slopes and plateaux (b=Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the percentage soil carbon recorded (refer to legend).

c) Folminkskop- open canopy



d) Folminkskop- closed canopy

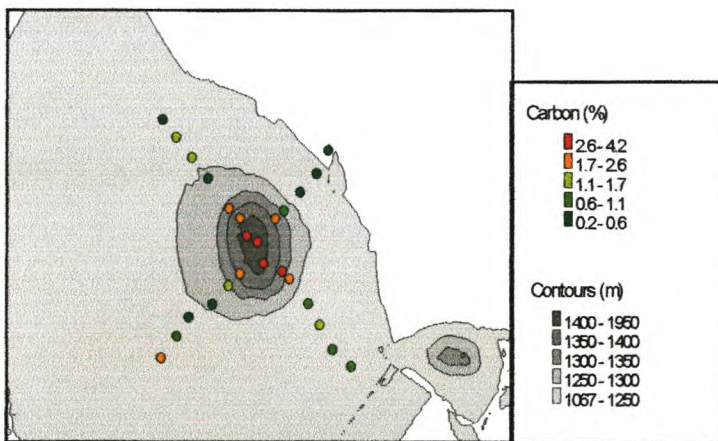
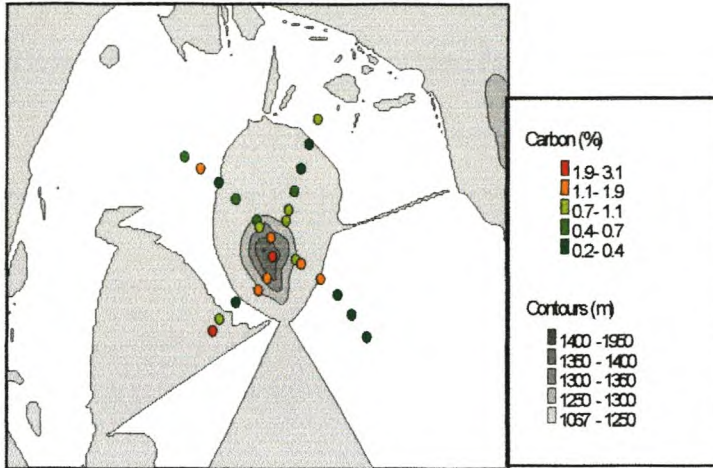


Figure 4.1 (cont): Thematic indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil carbon content (%) of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil carbon content at closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the percentage soil carbon recorded (refer to legend).

e) Buffelskop- open canopy



f) Buffelskop- closed canopy

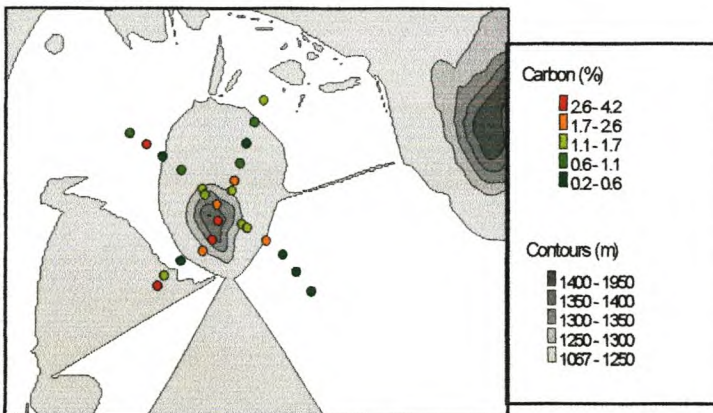


Figure 4.1 (cont): Thematic indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil carbon content (%) of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil carbon content at closed-canopy samples from flats, slopes and plateaux (f= Buffelskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the percentage soil carbon recorded (refer to legend).

4.4.2 Variation in soil phosphorus

One-Way Anova showed a significant difference in phosphorus levels between different habitats. Figure 4.2 illustrates that high phosphorus levels occurred on the flats compared to the slopes and plateaux for all the mesas ($p < 0.01$; $df = 2, 153$; $F = 6.7$). Phosphorus levels between open- (Figure 4.2a, c and e) and closed-canopy (Figure 4.2b, d and f) cover samples were not significantly different ($p = 0.9924$; $df = 1, 153$; $F = 0.0001$). The Buffelskop mesa had high phosphorus levels (up to 491 mg/kg for open-canopy cover samples and 561 mg/kg for closed-canopy cover samples) for all the different habitats.

a) Tafelberg- open canopy

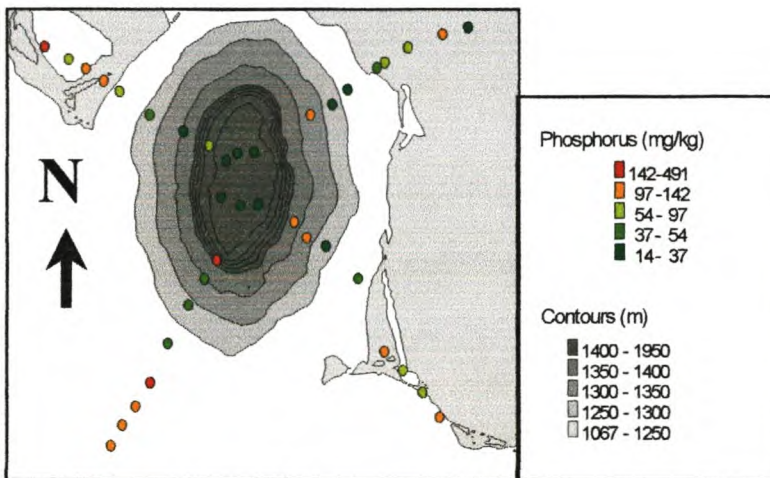
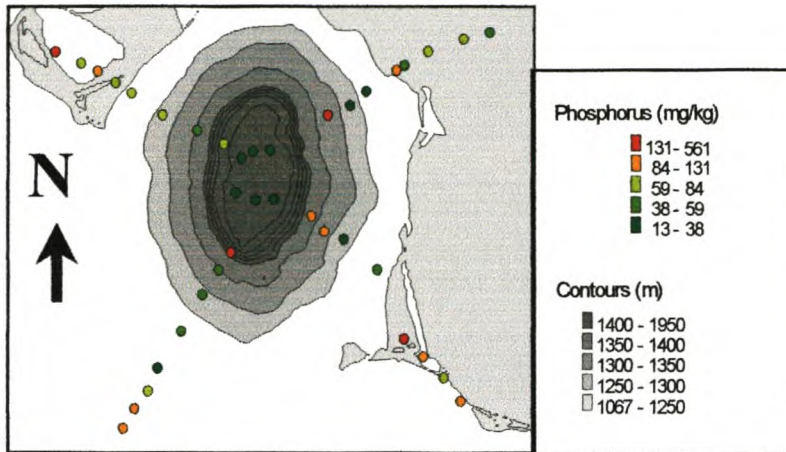


Figure 4.2: Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil phosphorus content of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil phosphorus content at closed-canopy samples from flats, slopes and plateaux. Circles represent the position and layout of permanent study sites on- and off- the mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil phosphorus (mg/kg) recorded (refer to legend).

b) Tafelberg- closed canopy



c) Folminkskop- open canopy

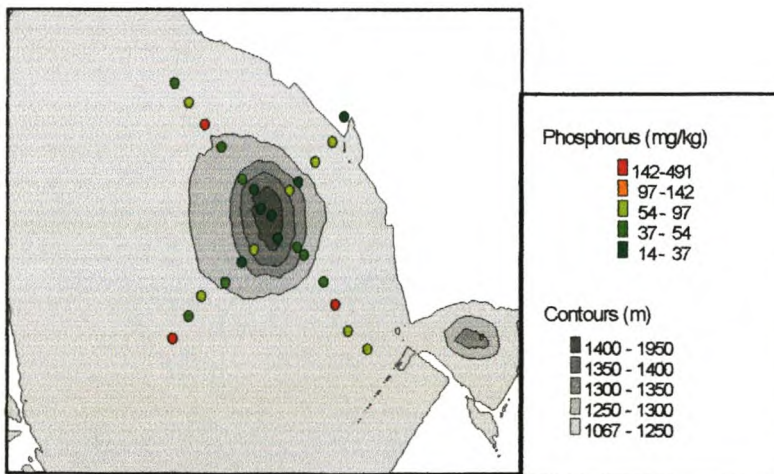
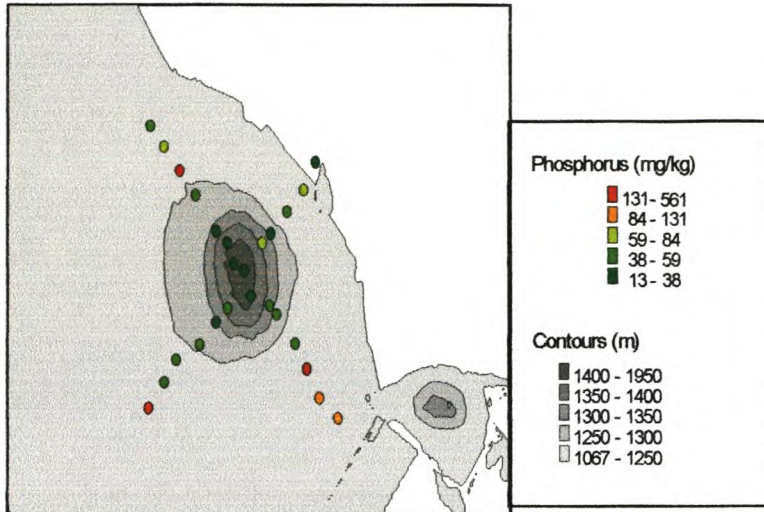


Figure 4.2 (cont): Thematic maps contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil phosphorus content of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil phosphorus content of closed-canopy samples from flats, slopes and plateaux (b= Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil phosphorus (mg/kg) recorded (refer to legend).

d) Folminkskop- closed canopy



e) Buffelskop- open canopy

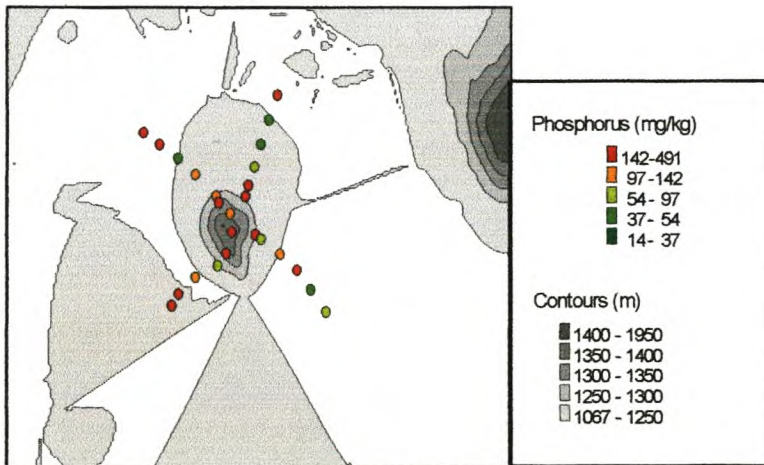


Figure 4.2 (cont): Thematic maps contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil phosphorus content of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil phosphorus content of closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil phosphorus (mg/kg) recorded (refer to legend).

f) Buffelskop- closed canopy

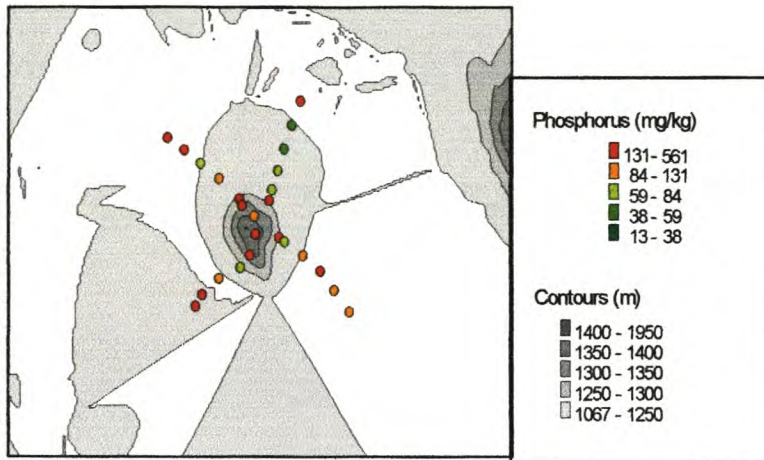


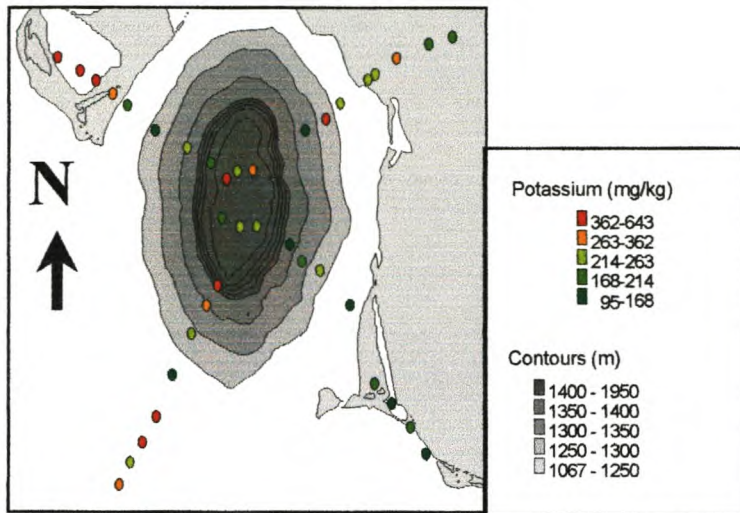
Figure 4.2 (cont): Thematic maps contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil phosphorus content of open-canopy samples from the flats, slopes and plateaux and soil phosphorus content of closed-canopy samples from flats, slopes and plateaux (d= Buffelskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil phosphorus (mg/kg) recorded (refer to legend).

4.4.3 Other essential macro- nutrients

4.4.3.1 Potassium

Soil potassium levels did not significantly differ for the different parts of the landscape ($p = 0.62$; $df = 2, 153$; $F = 0.5$). However, a significant difference in potassium level between open- and closed- canopy cover samples was recorded ($p < 0.05$; $df = 2, 153$; $F = 5.5$). High potassium levels of up to 979 mg/kg were recorded for closed-canopy cover samples (Figure 4.3b, d and f), whilst lower (up to 643 mg/kg) potassium levels were recorded for open-canopy samples (Figure 4.3a, c and e). Soil potassium for both open- and closed-canopy samples on the north-eastern and south-eastern flats were relatively lower in comparison with the rest of the habitats.

a) Tafelberg- open canopy



b) Tafelberg- closed canopy

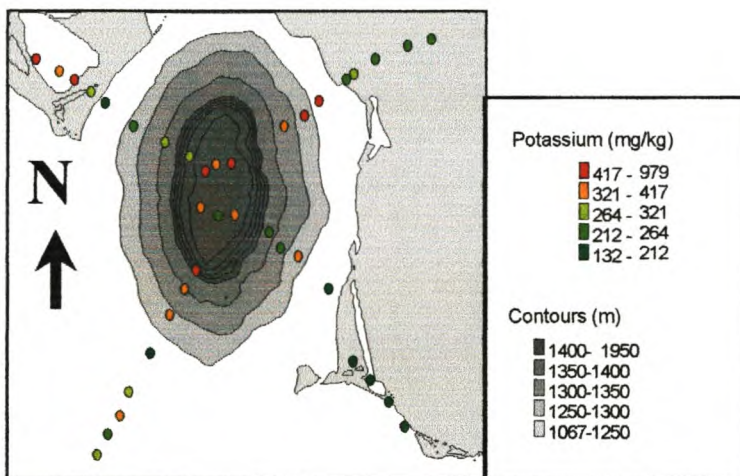
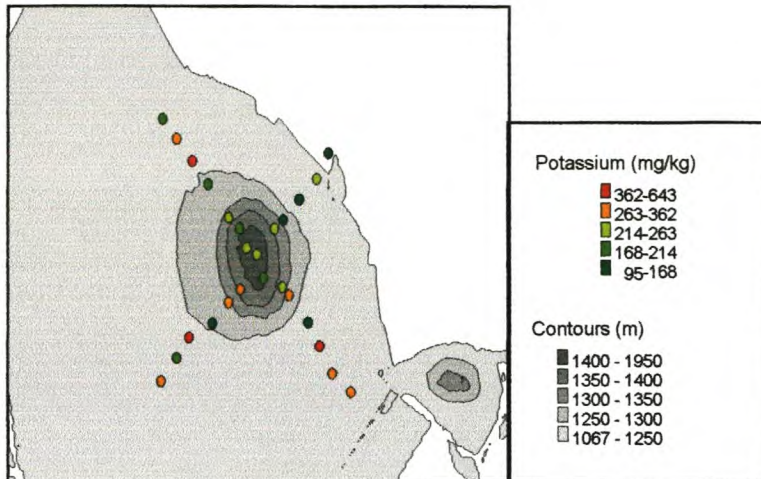


Figure 4.3: Thematic maps contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil potassium content of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil potassium content of closed-canopy samples from flats, slopes and plateaux (b= Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil potassium (mg/kg) recorded (refer to legend).

c) Folminkskop- open canopy



d) Folminkskop- closed canopy

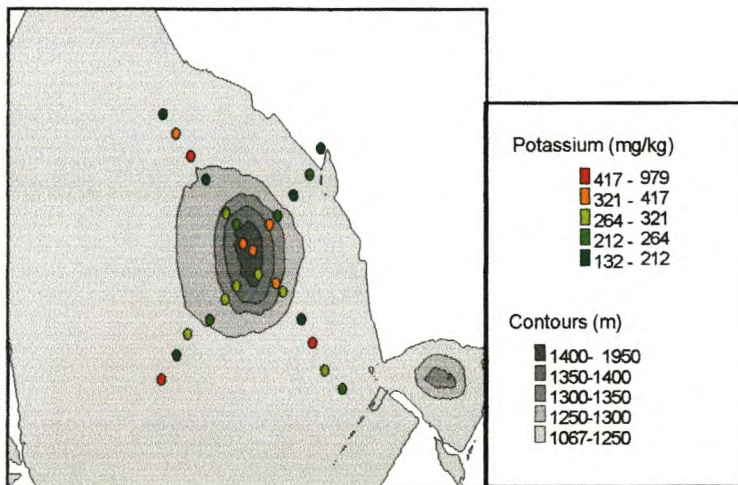
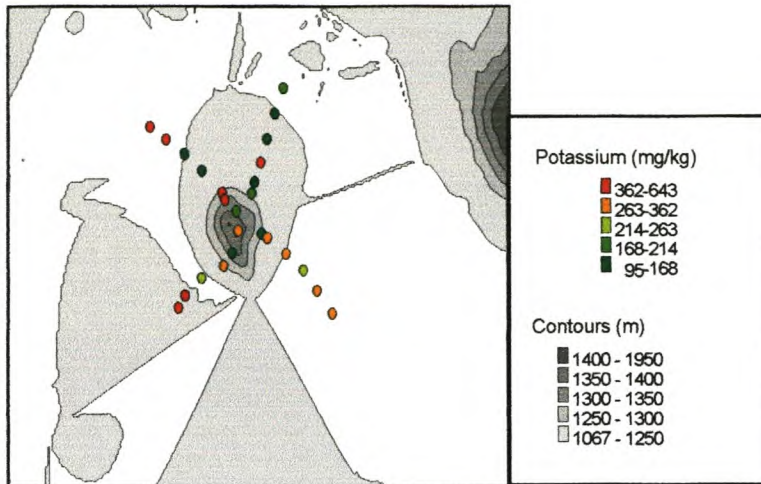


Figure 4.3 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil potassium content of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil potassium content of closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position and layout of permanent study sites on- and off-mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil potassium (mg/kg) recorded (refer to legend).

e) Buffelskop- open canopy



f) Buffelskop- closed canopy

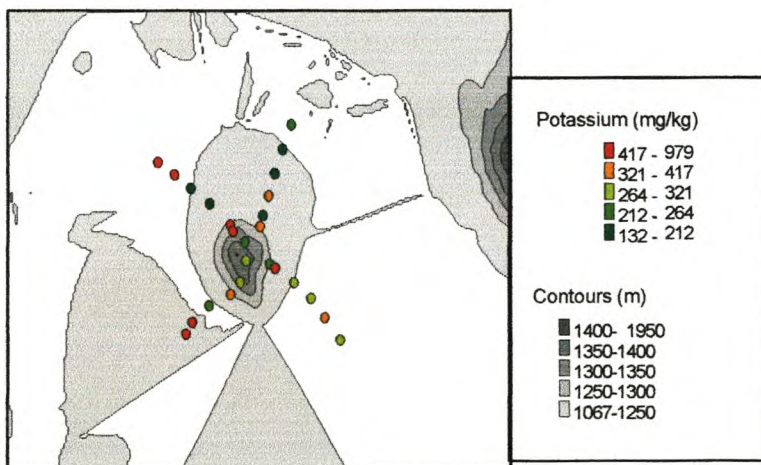


Figure 4.3 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil potassium content of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil potassium content of closed-canopy samples from flats, slopes and plateaux (f= Buffelskop). Circles represent the position and layout of permanent study sites on- and off-mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil potassium (mg/kg) recorded (refer to legend).

4.4.3.2 Calcium

One-Way Anova showed a significant difference in calcium content between the different habitats ($p < 0.05$; $df = 2, 153$; $F = 4.5$). Calcium content decreased from flats to the plateaux of all three mesas. However, no significant differences in calcium levels were recorded between open- and closed-canopy cover samples ($p = 0.4425$; $df = 1, 153$; $F = 0.6$). Low calcium levels (as little as 4.3 me %) between open- and closed-canopy cover samples were observed for all the mesas. Low soil calcium levels were also recorded under shrubs (Figure 4.4b) and at open-canopy cover sites samples (Figure 4.4a) on the flats surrounding the Tafelberg mesa, compared to the flats surrounding the Folminkskop and Buffelskop.

a) Tafelberg- open canopy

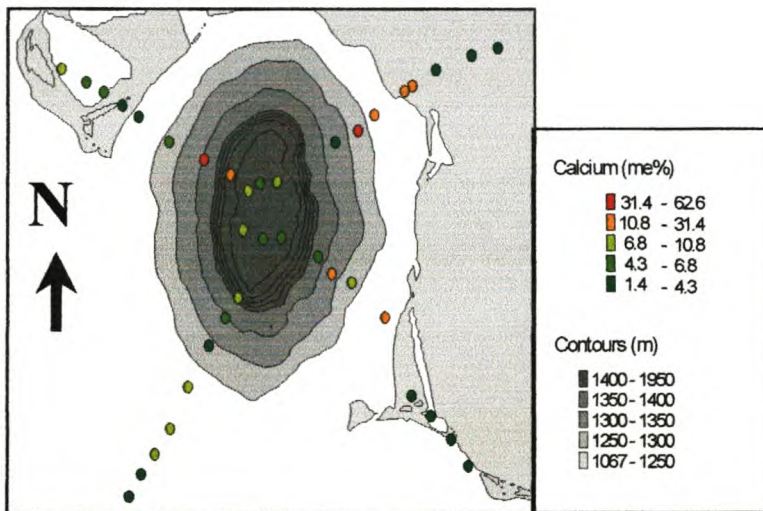
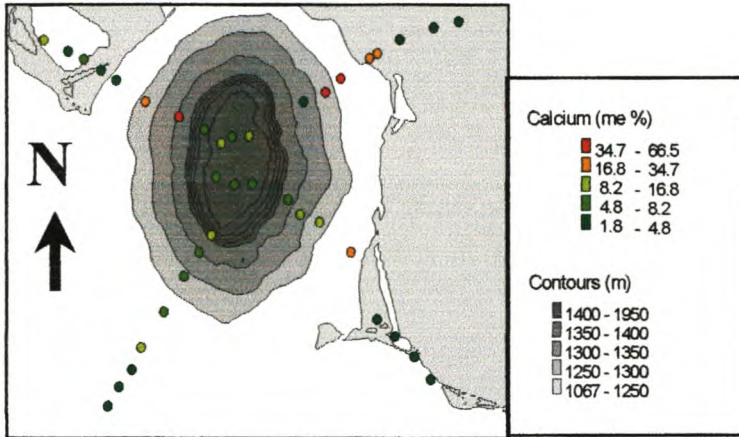


Figure 4.4: Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil calcium content of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil calcium content of closed-canopy samples from flats, slopes and plateaux. Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil calcium (ekivalent %) recorded (refer to legend).

b) Tafelberg- closed canopy



c) Folminkskop- open canopy

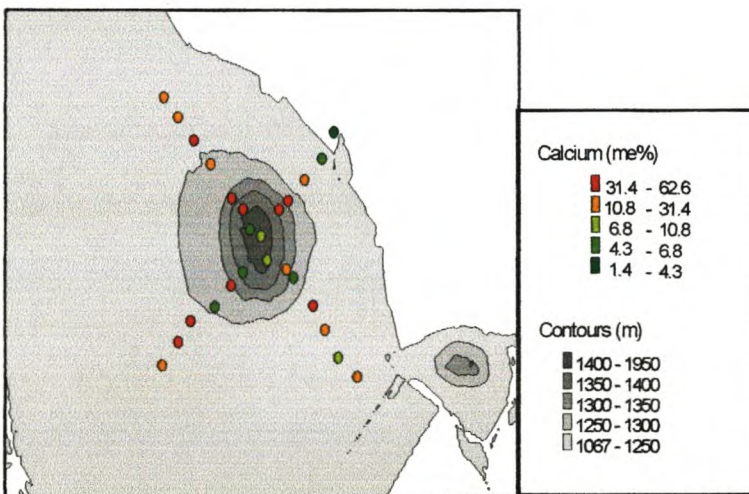
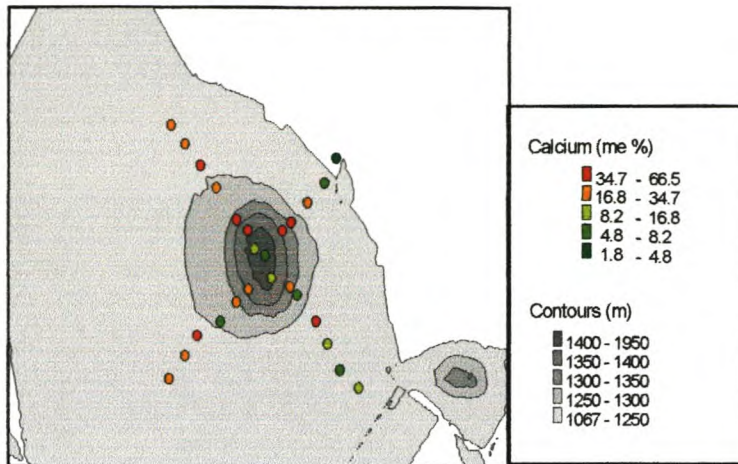


Figure 4.4 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil calcium content of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil calcium content of closed-canopy samples from flats, slopes and plateaux (b= Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil calcium (ekvivalent %) recorded (refer to legend).

d) Folminkskop- closed canopy



e) Buffelskop- open canopy

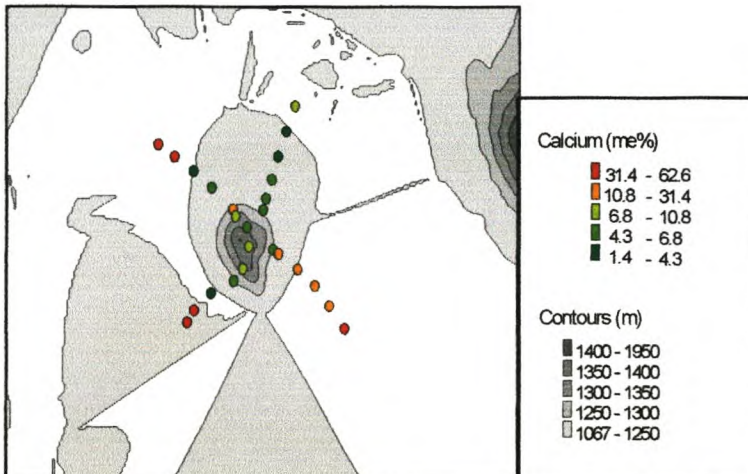


Figure 4.4 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil calcium content of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil calcium content of closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil calcium (ekivalent %) recorded (refer to legend).

f) Buffelskop- closed canopy

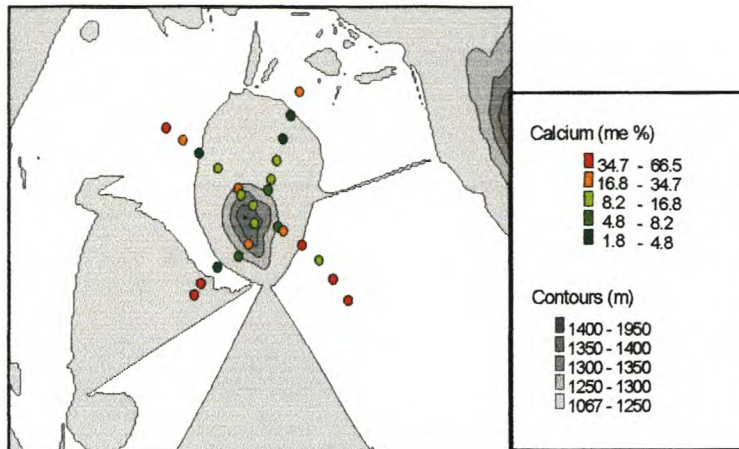
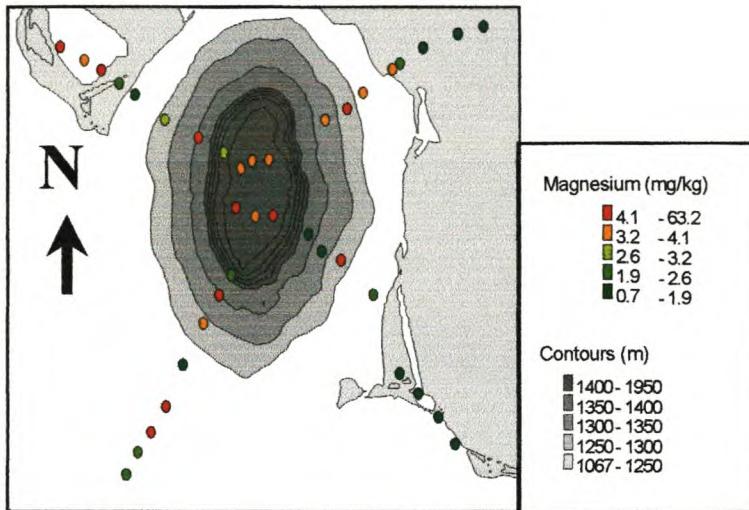


Figure 4.4 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil calcium content of open-canopy samples from the flats, slopes and plateaux and soil calcium content of closed-canopy samples from flats, slopes and plateaux (f= Buffelskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil calcium (ekivalent %) recorded (refer to legend).

4.4.3.3 Magnesium

On average, the magnesium content per site on flats (7 mg/kg) was significantly higher than that recorded on the slopes (3 mg/kg) and plateaux (4 mg/kg) for all the mesas ($p < 0.05$; $df = 2, 153$; $F = 3.0$) (Figure 4.5). However, there was no significant differences in magnesium content between open- and closed-canopy cover soils for the different mesas ($p = 0.72$; $df = 1, 154$; $F = 0.1$). Low soil magnesium levels (as little as 0.7 mg/kg) for open-canopy cover soil samples and closed-canopy cover soil samples (as little as 0.8 mg/kg) were recorded on the north-eastern and south-eastern flats of the Tafelberg mesa (Figure 4.5a and b).

a) Tafelberg- open canopy



b) Tafelberg- closed canopy

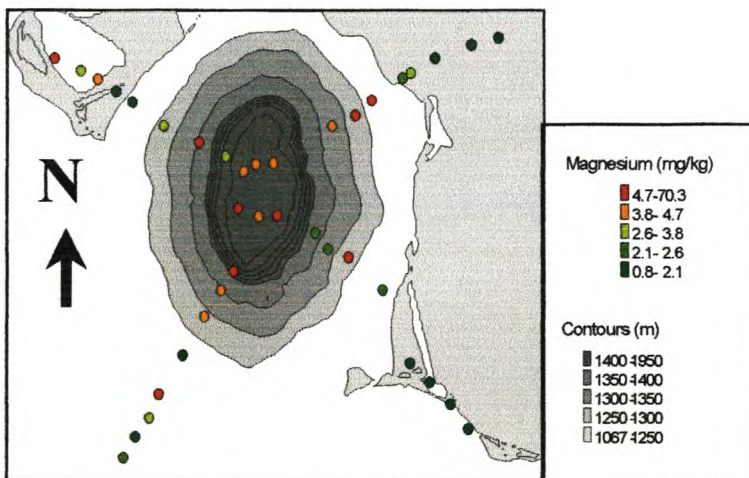
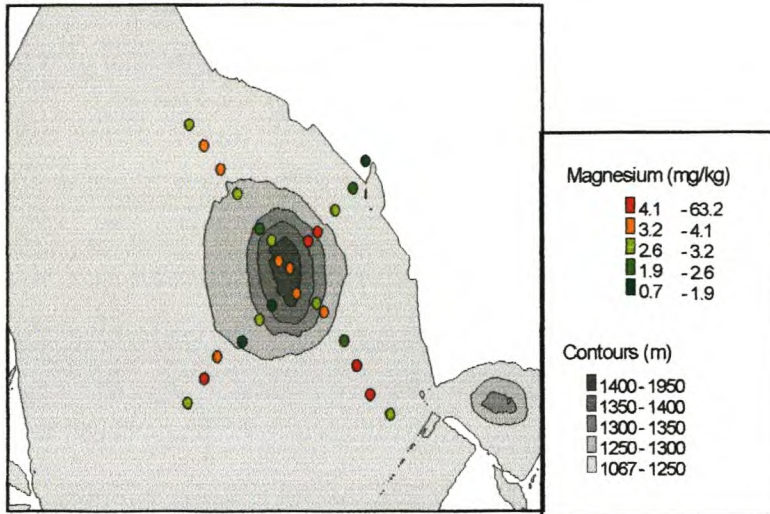


Figure 4.5: Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil magnesium content of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil magnesium content of closed-canopy samples from flats, slopes and plateaux (b= Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil magnesium (mg/kg) recorded (refer to legend).

c) Folminkskop- open canopy



d) Folminkskop- closed canopy

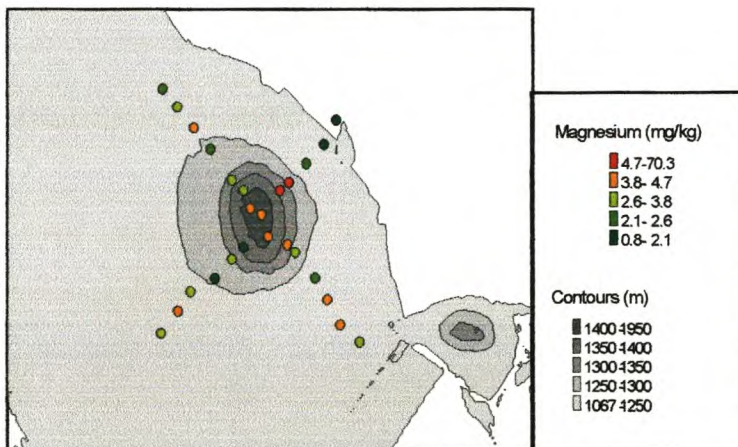
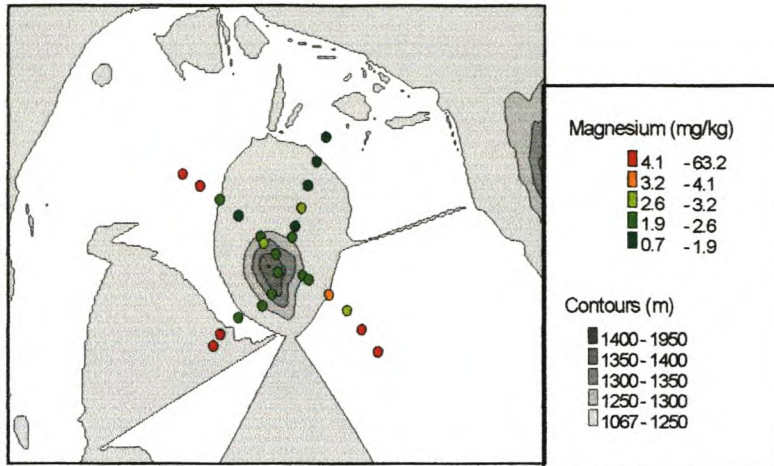


Figure 4.5 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil magnesium content of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil magnesium content of closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position and layout of permanent study sites on- and off-mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil magnesium (mg/kg) recorded (refer to legend).

e) Buffelskop- open canopy



f) Buffelskop- closed canopy

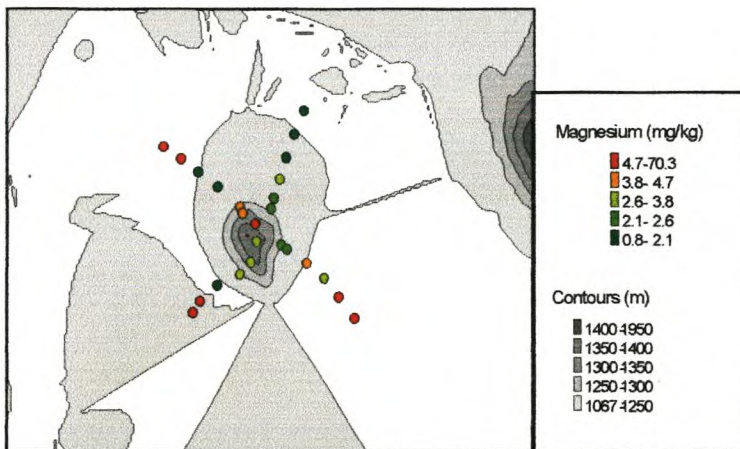


Figure 4.5 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil magnesium content of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil magnesium content of closed-canopy samples from flats, slopes and plateaux (f= Buffelskop). Circles represent the position and layout of permanent study sites on- and off-mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil magnesium (mg/kg) recorded (refer to legend).

4.4.3.4 Copper

Soil copper levels were found to be high on the plateaux of all three mesas when compared to the flats ($p < 0.001$; $df = 2, 153$; $F = 38.5$) (Figure 4.6). Copper levels, however, were not different between open- and closed-canopy cover soil samples ($p = 0.70$; $df = 1, 154$; $F = 0.2$). High soil copper levels were observed on the south-eastern flats of the Folminkskop mesa (Figure 4.6c and d).

a) Tafelberg- open canopy

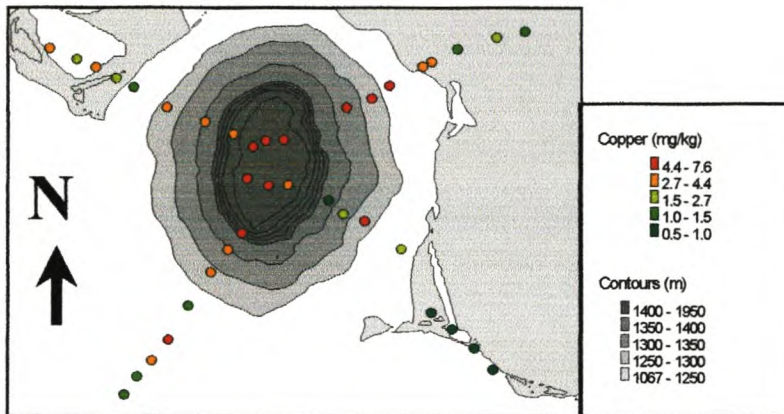
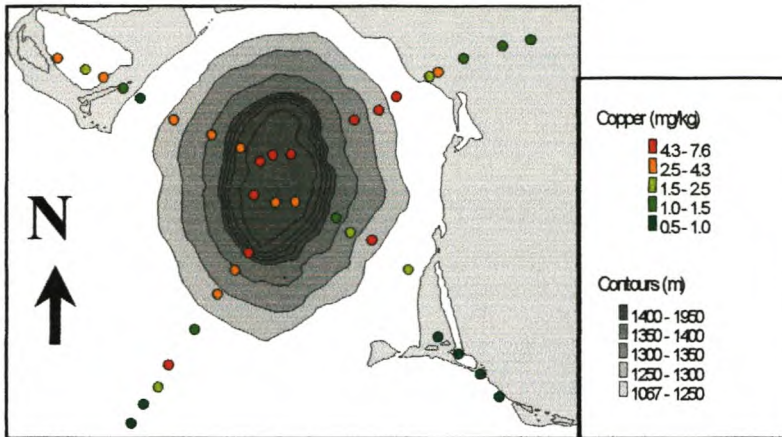


Figure 4.6: Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil copper content of open-canopy samples from the flats, slopes and plateaux (a= Tafelberg) and soil copper content of closed-canopy samples from flats, slopes and plateaux. Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil copper (mg/kg) recorded (refer to legend).

b) Tafelberg- closed canopy



c) Folminkskop- open canopy

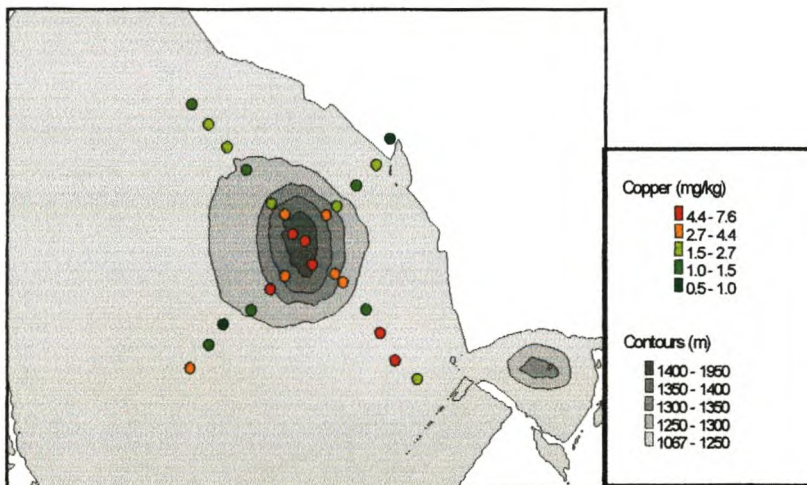
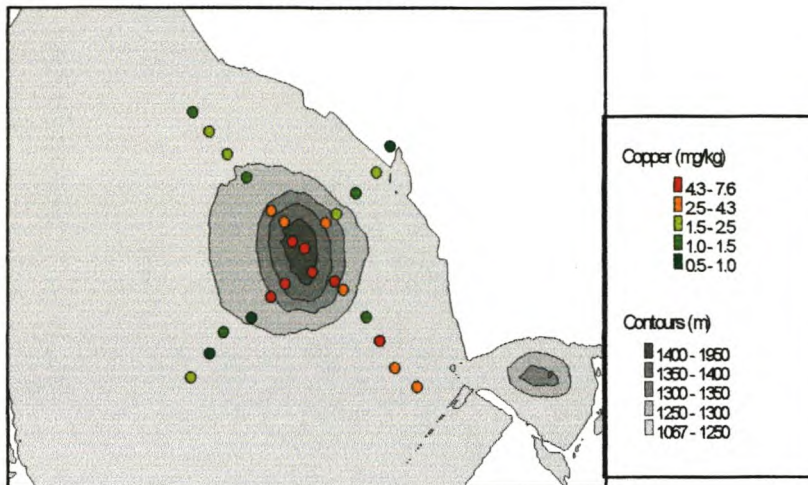


Figure 4.6 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil copper content of open-canopy samples from the flats, slopes and plateaux (c= Folminkskop) and soil copper content of closed-canopy samples from flats, slopes and plateaux (b= Tafelberg). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil copper (mg/kg) recorded (refer to legend).

d) Folminkskop- closed canopy



e) Buffelskop- open canopy

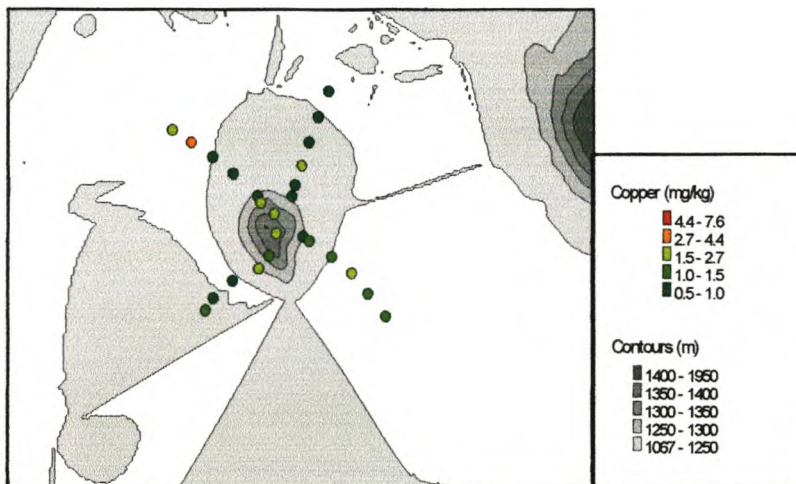


Figure 4.6 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil copper content of open-canopy samples from the flats, slopes and plateaux (e= Buffelskop) and soil copper content of closed-canopy samples from flats, slopes and plateaux (d= Folminkskop). Circles represent the position an layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil copper (mg/kg) recorded (refer to legend).

f) Buffelskop- closed canopy

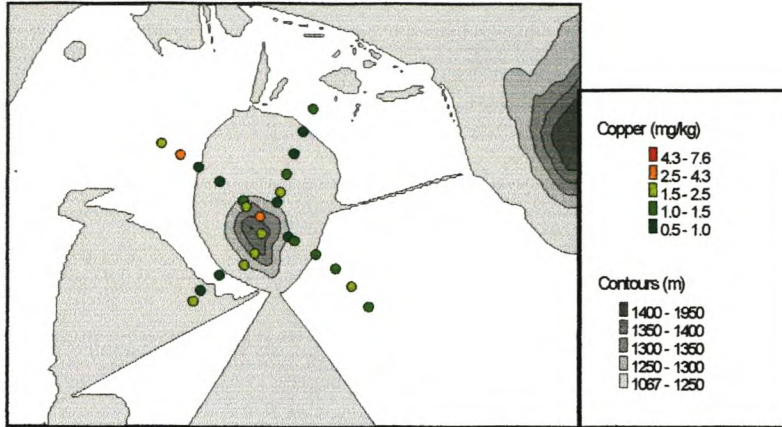


Figure 4.6 (cont): Thematic maps indicating contours for the three mesas (Tafelberg, Folminkskop and Buffelskop) and their surroundings. Data represents soil copper content of open-canopy samples from the flats, slopes and plateaux and soil copper content of closed-canopy samples from flats, slopes and plateaux (f= Buffelskop). Circles represent the position and layout of permanent study sites on- and off- mesas, located on four compass half points (NW; SW; NE; SE). The colour at each study site represents the soil copper (mg/kg) recorded (refer to legend).

Table 4.1: Means \pm standard error of macro-nutrients of soils removed from open- and closed-canopy sites at different habitats from all three mesas in the Middelburg district of the Eastern Cape. The units used to express concentration of each macro-nutrients were Carbon= C (%); Phosphorus= P (mg/kg); Potassium= K (mg/kg); Calcium= Ca (mg/kg); Magnesium= Mg (mg/kg); Copper= Cu (mg/kg).

Mesas	Habitat	Area	Soil chemical properties						Sample size (n)
			C (%)	P (mg/kg)	K (mg/kg)	Ca (me%)	Mg (mg/kg)	Cu (mg/kg)	
Tafelberg	Flat	Open	0.6 \pm 0.4	110.9 \pm 58.9	291.8 \pm 146.2	4.9 \pm 3	2.5 \pm 1.5	2 \pm 1.4	16
		Closed	0.9 \pm 0.5	85.7 \pm 39.4	279.1 \pm 101.6	6 \pm 5.7	2.4 \pm 1.4	1.6 \pm 1.1	
	Slope	Open	1.4 \pm 0.6	71.2 \pm 61.7	240.2 \pm 128.9	14 \pm 13.7	3.3 \pm 1.7	3.6 \pm 1.7	16
		Closed	1.9 \pm 0.6	81.8 \pm 69.9	311.8 \pm 107.9	18 \pm 18.8	4 \pm 2.2	3.5 \pm 1.7	
	Plateau	Open	2.5 \pm 0.4	20.3 \pm 4.8	270 \pm 80.7	6.8 \pm 0.4	4.1 \pm 0.5	4.7 \pm 0.3	6
		Closed	3.3 \pm 0.3	23.5 \pm 3.9	370.8 \pm 99.1	8.1 \pm 1	4.4 \pm 0.4	4.2 \pm 0.5	
Folminkskop	Flat	Open	0.7 \pm 0.3	110.2 \pm 102.9	282.8 \pm 119.1	27 \pm 17	3.6 \pm 1.3	2.3 \pm 1.5	12
		Closed	0.9 \pm 0.5	106.8 \pm 94.9	285.1 \pm 111.3	25.1 \pm 16.3	3.2 \pm 0.9	2 \pm 1.1	
	Slope	Open	1.6 \pm 0.5	45 \pm 14.4	256.5 \pm 52.6	26 \pm 18.8	2.6 \pm 0.7	3.9 \pm 1.2	6
		Closed	2.3 \pm 0.7	40 \pm 8.4	292.7 \pm 36.3	27.1 \pm 16.4	3 \pm 0.7	4.3 \pm 1.2	
	Plateau	Open	2.3 \pm 0.3	25.3 \pm 6.8	215.7 \pm 19.6	6.8 \pm 0.4	3.3 \pm 1	6.6 \pm 1.3	3
		Closed	3.6 \pm 0.6	21 \pm 8	351.3 \pm 56.7	8.4 \pm 0.6	4 \pm 0.1	6.2 \pm 1.2	
Buffelskop	Flat	Open	0.8 \pm 0.7	171.5 \pm 104.5	348.5 \pm 175.7	28.9 \pm 19.7	16.6 \pm 19.1	1.4 \pm 1	11
		Closed	1.4 \pm 1.3	180.4 \pm 114.6	421.7 \pm 253.5	32.7 \pm 21.3	17.9 \pm 21.1	1.6 \pm 1.1	
	Slope	Open	1.1 \pm 0.3	189.5 \pm 154.9	276.7 \pm 99.9	12.9 \pm 10.4	2.4 \pm 0.4	1.4 \pm 0.5	6
		Closed	1.8 \pm 0.7	231.8 \pm 179.9	409.8 \pm 132	18.6 \pm 11	3.2 \pm 0.7	1.6 \pm 0.3	
	Plateau	Open	1.9 \pm 0.1	145.5 \pm 16.3	235 \pm 67.9	7 \pm 0.7	2.3 \pm 0.4	2 \pm 0.2	2
		Closed	2.5 \pm 0.4	124.5 \pm 48.8	272.5 \pm 65.8	8.9 \pm 0.7	6.2 \pm 4.9	2.5 \pm 0.1	

4.4.4 Micro- nutrients (Trace elements)

Table 4.2 summarizes data for all the soil micro-nutrient elements removed from micro-sites (open-and closed-canopy) at different habitats (flats, slopes, plateaux) of all three mesas in the Middelburg District of the Eastern Cape. The units used the express concentration of each micro-nutrients were Zn (mg/kg); Manganese (mg/kg); Boron (mg/kg).

Soil zinc levels were significantly different for flats, slopes and plateaux ($p < 0.01$; $df = 2, 153$; $F = 5.7$). The levels of zinc increased gradually with an increasing altitude, peaking on the plateaux of mesas. A highly significant difference was found in zinc levels between open- and closed-canopy soil samples ($p < 0.001$; $df = 1, 153$; $F = 23.6$). High soil zinc levels were consistently found in closed-canopy samples for all habitats.

Soil manganese levels showed a highly significant difference between the different habitats ($p < 0.001$; $df = 2, 153$; $F = 29.7$). Manganese increased with increasing altitudinal landscape. Statistical analyses showed no significant differences in manganese levels between open- and closed-canopy soil samples ($p = 0.7414$; $df = 1, 153$; $F = 0.11$). Manganese levels in both open- and closed-canopy soil samples on the Buffelskop mesa showed an even distribution between the different parts of the landscape.

No significant differences in boron levels were found at different habitats for all three mesas ($p = 0.5560$; $df = 2, 153$; $F = 0.6$). However, a highly significant difference was found in boron levels between open- and closed-canopy soil samples ($p < 0.01$; $df = 1, 154$; $F = 7.1$).

Table 4.2: Means \pm standard error of micro-nutrients soil samples removed from micro-sites (open-and closed-canopy) at different habitats (flats, slopes, plateaux) of all three mesas in the Middelburg District of the Eastern Cape. The units used the express concentration of each micro-nutrients were Zinc= Zn (mg/kg); Manganese= Mn (mg/kg); Boron= B (mg/kg) removed from open- and closed-canopy sites at different habitats for all three mesas.

Mesas	Habitat	Micro site	Soil chemical properties			
			Zn (mg/kg)	Mn (mg/kg)	B (mg/kg)	Sample size (n)
Tafelberg	Flat	Open	1.3 \pm 0.8	145.2 \pm 95.9	0.5 \pm 0.3	16
		Closed	1.9 \pm 1.3	125.8 \pm 89.3	0.5 \pm 0.4	
	Slope	Open	1 \pm 0.5	150.4 \pm 60.4	0.5 \pm 0.3	16
		Closed	1.6 \pm 0.7	147.2 \pm 62.9	0.8 \pm 0.3	
	Plateau	Open	1.9 \pm 0.5	330.6 \pm 69	0.8 \pm 0.1	6
		Closed	3.1 \pm 0.7	325 \pm 76.2	0.9 \pm 0.2	
Folminkskop	Flat	Open	1 \pm 0.5	131.8 \pm 85.1	0.5 \pm 0.2	12
		Closed	1.3 \pm 0.7	116.5 \pm 68	0.6 \pm 0.3	
	Slope	Open	1 \pm 0.3	141 \pm 50.2	0.5 \pm 0.1	6
		Closed	1.8 \pm 0.6	148.4 \pm 48.1	0.7 \pm 0.2	
	Plateau	Open	1.7 \pm 0.7	250.7 \pm 57.9	0.6 \pm 0.1	3
		Closed	2.3 \pm 0.3	260.7 \pm 65.1	1.1 \pm 0.1	
Buffelskop	Flat	Open	1.1 \pm 0.4	90.1 \pm 81.6	1.2 \pm 0.9	11
		Closed	2.6 \pm 2.2	94.3 \pm 77	1.2 \pm 0.9	
	Slope	Open	1.4 \pm 0.7	70.1 \pm 7.4	0.5 \pm 0.1	6
		Closed	2.4 \pm 1.1	75.9 \pm 13	1.1 \pm 0.2	
	Plateau	Open	1.8 \pm 0.2	83.6 \pm 22.5	0.5 \pm 0.03	2
		Closed	2.1 \pm 0.5	100.5 \pm 15.5	0.7 \pm 0.1	

4.4.5 Variation in soil pH

A highly significant difference was found in soil pH levels for the different habitats ($p < 0.001$; $df = 2, 153$; $F = 17.6$). The trend was that pH values decreased with an increase in gradient. However, variation in soil pH does not appear to be significantly different between open- and closed-canopy soil samples for all three mesas ($p = 0.6998$; $df = 1, 154$; $F = 0.2$). Higher pH values (≥ 7) occurred in both open- and closed-canopy soil samples on the flats of the Folminkskop and Buffelskop mesas compared to that on the flats of the Tafelberg mesa (Figure 4.7).

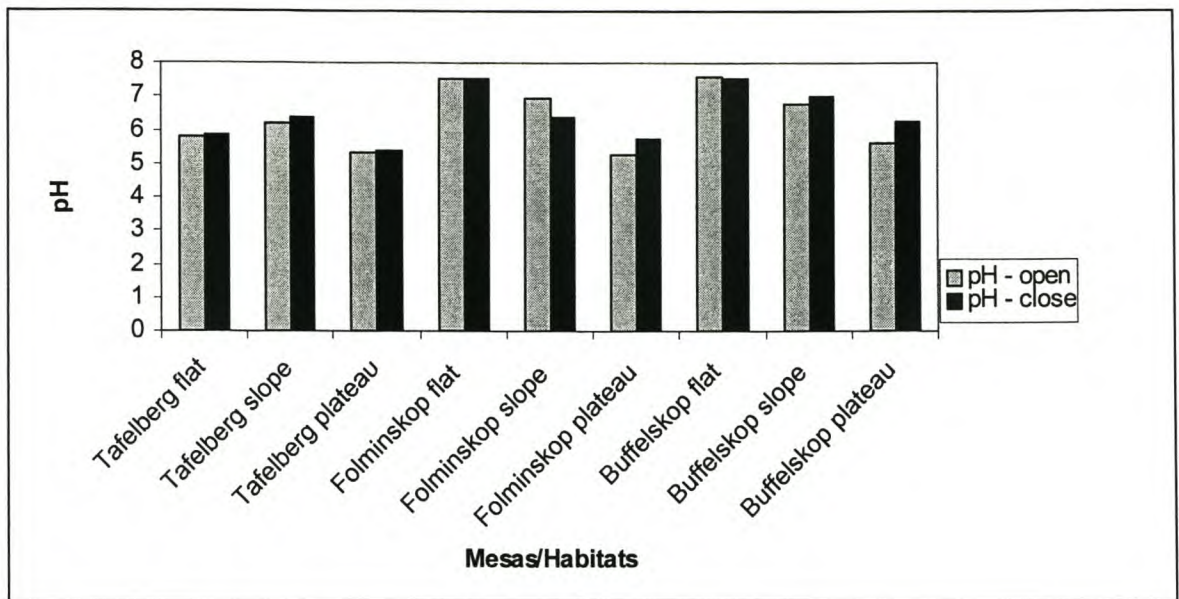


Figure 4.7: Comparison of soil pH from both open-and-closed canopy soil samples from Tafelberg, Folminkop and Buffelskop with respect to their different habitats.

4.4.6 Variation in soil texture

Soil texture varied considerably between the flats, slopes and plateaux of all three mesas (Figure 4.8). A significant difference in percentage sand per study site was found for the different habitats of the three mesas ($p < 0.01$; $df = 2,153$; $F = 6.6$). In particular, sandy soils dominated the flats. However, no significant differences in percentage sand were recorded between open- and closed-canopy soil samples for all three mesas ($p = 0.139$; $df = 1,154$; $F = 2.2$). The percentage clay content per site differed significantly for the different habitats of the mesas ($p < 0.001$; $df = 2,153$; $F = 8.2$). A higher percentage clay content per site was more evident on the plateaux of the Tafelberg and Folminkop mesa than on the plateau of the Buffelskop mesa. Unlike for the Buffelskop mesa, slopes on the Tafelberg and Folminkop mesas in turn had consistently lower percentage clay. No significant differences were found for clay content between open- and closed-canopy soil samples ($p = 0.139$; $df = 1,154$; $F = 2.2$). Whilst there were no significant differences in silt content between open- and closed-canopy soil samples ($p = 0.179$; $df = 1,154$; $F = 1.8$), the flats and slopes of all three mesas showed consistent lower percentage silt levels than the plateaux ($p < 0.05$; $df = 2,153$; $F = 4.2$).

A highly significant difference in percentage stone content was found at different parts of the landscape ($p < 0.001$; $df = 2, 153$; $F = 8.1$). Soil samples showed higher stone content on the slopes compared to the plateaux (Figure 4.8). However, no significant difference in percentage stone content was found between open- and closed-canopy soil samples of all the mesas.

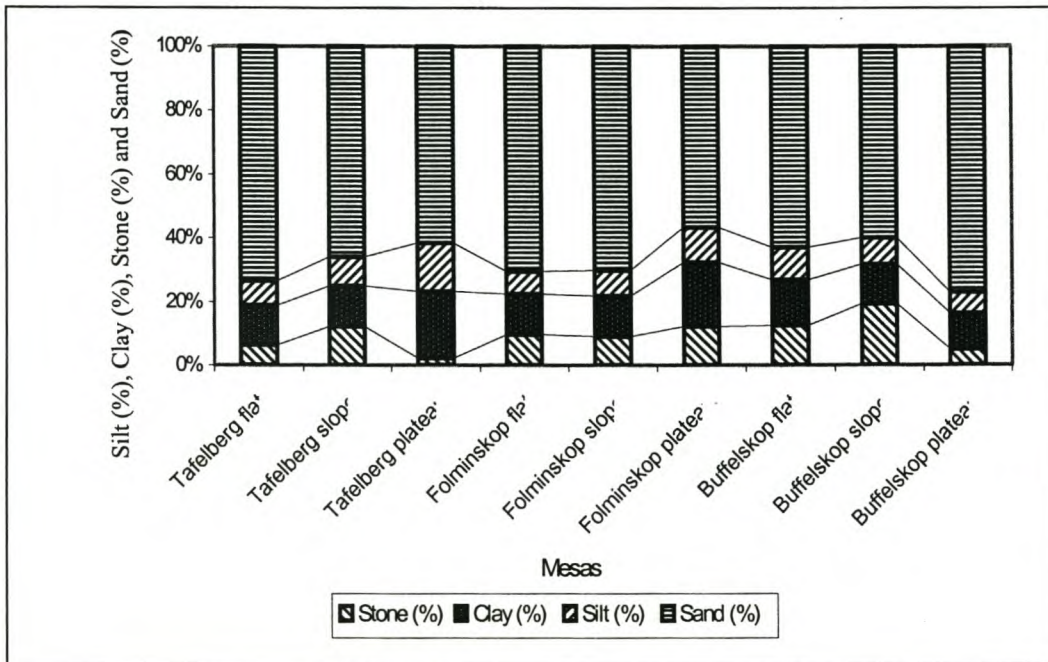


Figure 4.8: Comparison of percentage soil texture ratios from both open-and closed canopy samples, from the flats, slopes and plateaux of all mesas (Tafelberg, Folminkop and Buffelskop). Soil texture classes are silt, clay, stone and sand.

4.4.7 Assessment of soil condition on- and off- Tafelberg Mesa

4.4.7.1 Stability

ANOVA statistical analysis showed that the stability of soils on the plateaux was significantly reduced compared to the flats and slopes of the Tafelberg mesa ($p < 0.001$; $df = 2, 147$; $F = 52.1$) (Figure 4.9a). The mean values of soil stability for flats and slopes were at least twice as much as the soil stability value for the plateaux (Figure 4.10a).

4.4.7.2 Infiltration

The infiltration on the flats and slopes was also significantly higher than that recorded on the plateau of the Tafelberg mesa ($p < 0.001$; $df = 2, 147$; $F = 79.3$) from the flats and slopes, but no differences were found between flats and slopes (Figure 4.9b).

4.4.7.3 Nutrient status

The nutrient status of soil samples followed the same pattern to that of soil stability and infiltration (Figure 4.9c). Nutrients found on the plateau were significantly lower on the plateau of the Tafelberg mesa than that found on the flats and slopes ($p < 0.001$; $df = 2, 147$; $F = 37.8$).

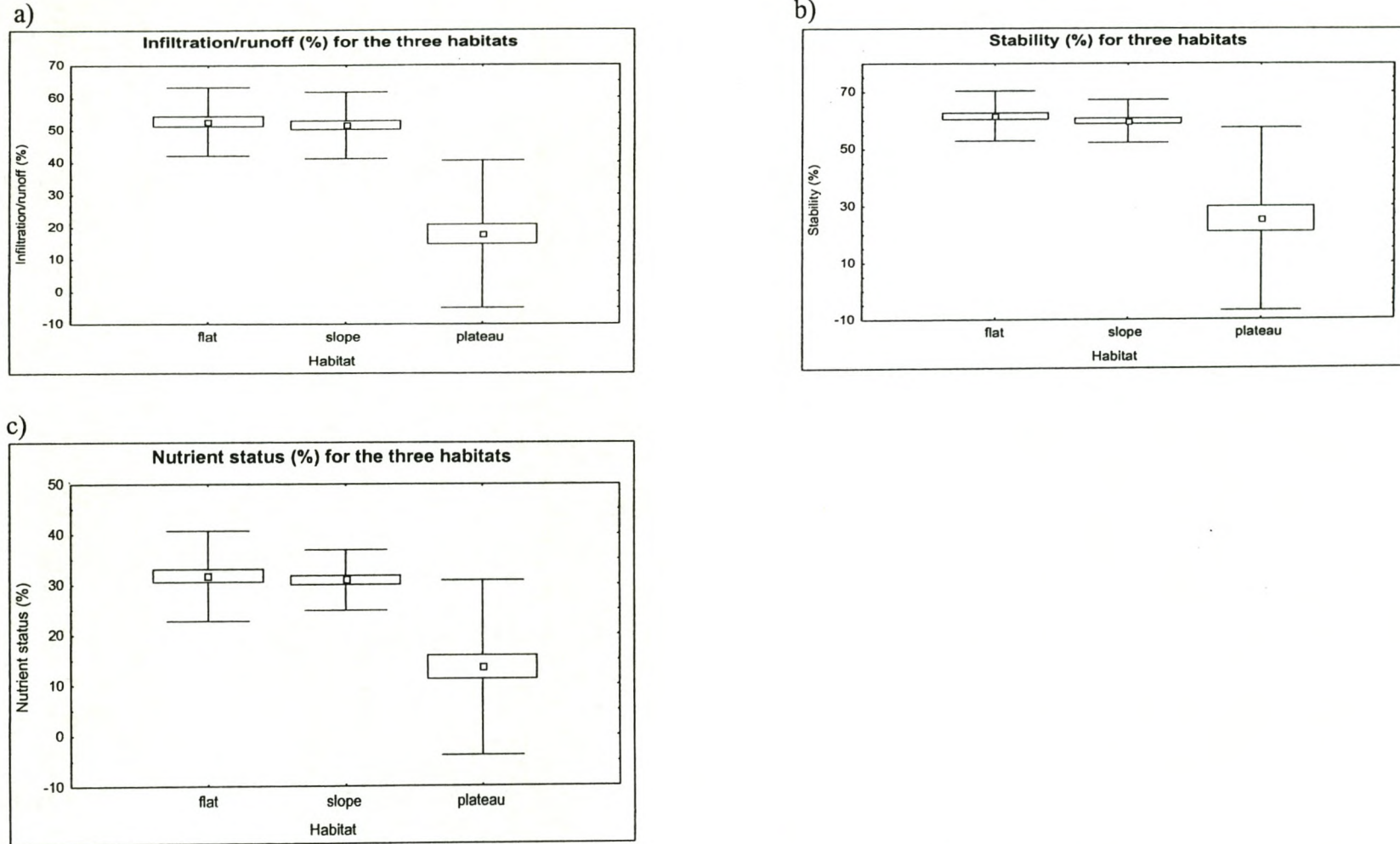


Figure 4.9: Infiltration, soil stability and nutrient status (a, b and c respectively) across the flats, slopes and plateau of Tafelberg. These three soil surface condition categories are represented by percentages.

4.5 Discussion

Whilst scientific literature suggests that biotic interactions drive vegetation dynamics in semi-arid regions (Yeaton and Esler 1990), several research studies have suggested vegetation-soil relationships as the possible cause for vegetation change at a variety of levels (Esler and Cowling 1993; Olsvig-Whittaker 1988; Wierenga *et al.* 1987). This study explored the variation in soil physical and chemical factors at a local and landscape scale. At a local scale, biotic interactions such as grazing, are expected to play a role in determining soil properties, while at a landscape scale, geomorphology is likely to play an important role. A variety of soil properties (carbon, phosphorus, calcium magnesium, copper and manganese) varied significantly over different parts of the landscape explaining vegetation patterns described by (Pienaar 2002; Jones 2000) at the same sites. This study also found that at the landscape level, soils from mesas and their surrounding flats showed significant variation in soil texture. Significant changes in soil for particularly carbon, potassium, zinc and boron elements were a consequence of local scale due to land use.

4.5.1 Landscape scale

The primary geology of the study area includes dolerite, mudstone and sandstone mesas that are surrounded by low-lying flats of alluvial and colluvial material. These mesas are remnants of an eroded African surface and are well known for their dolerite caps with fine-grained sand stone and red and green-gray, mudstone slopes (Geological Survey 1996). The dolerite is hard, but when it erodes it exposes the softer sediments that erode more quickly. In some situations these caps have completely eroded away of which Buffelskop is a classical example of such mesas. Both Tafelberg and Folminkskop are capped with dolerite whilst Buffelskop, is dominated by sandstone.

Soil organic matter (SOM) is a key component of any ecosystem and any variation in its abundance and nature may have profound effects on soil processes (Du Preez and Snyman 1993). SOM also improves water infiltration (Allison 1973). Soil carbon is the largest single constituent of soil organic matter (Sparks 1990; Weier *et al.* 1982). Snyman and Fouche (1991) noted that dry matter production declines in the arid and semi-arid regions as veld conditions declines so that less organic matter is added to the soil. Albaladejo (1990) and Diaz *et al.* (1994) demonstrated that destruction of plant cover (degradation) leads to a disruption of carbon levels, and therefore causing soil

organic matter to decrease. Once soil organic matter is lost, recuperation is a slow process in the Karoo and carbon is needed for its restoration (Milton *et al.* 1994). The decline of soil organic matter is an important cause of concern and the question arises as to how far can the organic matter content of a soil be depleted before degradation is irreversible? Soil carbon content was found to be low on the flats relative to the slopes and plateau, and, low in open-canopy micro-sites relative to closed-canopy sites for all three mesas. Clearly if one considers soil carbon alone, the mesas in the Middelburg District may be regarded as less degraded habitat islands and flats more degraded and are in dire need of restoration. The high carbon levels found on the plateaux and slopes of all three mesas were possibly due to a higher density of emergent rocks (which trap debris), denser plant canopy cover and lower intensity of grazing. High grazing intensity does not necessarily result in soil organic matter, it is a combination of intensity, time in a camp and rest period (Bauer *et al.* 1987; Du Preez and Snyman 1993).

Phosphorus is an essential nutrient for plant growth and plays a very important role in plant metabolism in relation to energy transformation (Weier *et al.* 1982). Phosphorus is returned to the soil through the breakdown of organic litter (Jones 2000). Sites with low levels of phosphorus could be a respond to overgrazing by livestock (Black 1957; Dean 1992; Perkins and Thomas 1993), since Day and Ludeke (1993) found that areas with high animal activity and consequently less leaf litter on soils, may possibly lead to lower levels of phosphorus ions moving back into the soil. Buckman and Brady (1969) speculated that the low levels of phosphorus recorded on the hill slopes are primarily a result of soil erosion mechanism.

Potassium is required in large amounts by plants (Marshner 1995). According to Brady (1990) and Galston *et al.* (1980), potassium levels in mineral soils are generally high, but do not appear to be toxic to plants or animals at these levels. The low potassium levels on the north-eastern and south-eastern sites compared to other sites on the flats of the Tafelberg mesa could possibly be a result of continued leaching of the sandy soils at these sites and is supported by the presence of drainage lines (Brady 1990).

Soil calcium is a key determinant of plant distribution in the Succulent Karoo Biome (Esler and Cowling 1993). I speculate that the higher than average (8.2 me %) calcium levels on the north-western, south-western and south-eastern flats of the smaller

Folminkskop and Buffelskop mesas could be the result of organic matter decay accumulated at these sites. These high levels were also attributed by past use of ostrich camps by the farmers. The average calcium distribution was relatively uniform at different parts of the Tafelberg mesa.

The function of magnesium in plants is mainly related to photosynthesis (Marschner 1995) and was considered to be an important edaphic factor influencing plant distribution in semi-arid environments (Esler and Cowling 1993). As suggested by Salisbury and Ross (1992), the magnesium levels in soils at a landscape level of mesas were enough to allow plant growth on- and off- the mesas. In particular, it is suggested that soils in and along drainage lines are sandy with low conductivity, little organic matter and low magnesium levels (Dean and Yeaton 1993). Large drainage lines probably caused suppressed magnesium levels on the north-eastern and south-eastern flats on particularly the Tafelberg mesa. Stokes (1999) also suggested that lower levels of magnesium are caused by the removal of topsoil through erosion and grazing effect on vegetation cover.

Copper is essential for plant physiological processes including respiration, cell wall metabolism and photosynthesis (Pais and Jones 1997). Copper is readily available for plant use, especially in acidic soils (Brady 1990) and can lead to copper toxicity problems in soils that are very acidic (Jones 2000). High copper levels found on slopes and plateaux of mesas support Burke's (2000) suggestion that geomorphological factors contribute to changes in copper levels at different parts of the landscape. Changes in veld condition also contribute to low copper levels in semi- arid soils (Du Preez and Snyman 1993; Schröder 1959). Copper deficiency in soils and plants can cause several debilitating diseases in livestock (Schröder 1959), including reduced growth rate and negative appearance of wool, hair and fur.

According to Pais and Jones (1997), low zinc levels are most likely to occur on leached sandy soils, low in organic matter content, and soils high in phosphorus. This study confirmed that low zinc levels on flats surrounding the mesas were accompanied by high soil phosphorus levels.

This study found that high levels of manganese occur on the plateaux of the Tafelberg and Folminkskop mesas where low pH values were recorded. Manganese levels increased significantly with a decrease in soil pH. Reasons for high manganese were most likely due to the different dissimilarities in soil nutrient content and soil texture.

Boron plays an important role in normal plant development (Weier *et al.* 1982) and plant metabolism (Kabata–Pendias and Pendias 1984; Pais and Jones 1997). The cause of boron deficiency includes death of meristematic cells, inhibition of root and shoot elongation and leaching of boron from sandy soils (Marschner 1995). This study confirmed the suggestion that boron deficiency is likely to occur in soils with low organic matter (Pais and Jones 1997).

Soil pH is known to affect the rate of decomposition of soil organic material and availability of nutrients for plant uptake (Brady 1997). It is the most frequently measured and quoted characteristic in ecological and agricultural soil literature (Jeffrey 1987). The availability of most nutrients is usually directly or indirectly affected by soil acidity (Pearcy *et al.* 1989). In this study, phosphorous levels increased with an increase in soil pH. The urine and dung pellets on the flats could, therefore, possibly contribute to the high soil pH levels.

4.5.2 Local scale

Unlike the uniform distribution of phosphorus, high levels of carbon measured for closed-canopy micro-sites were most likely due to accumulated plant and animal detritus trapped under closed-canopy patches (Dean and Milton 1993; Jones 2000). Ants, wind and water can move leaf litter, dung pellets, seeds and other debris along soil surfaces. These sources of carbon are then trapped by fallen branches, plant clumps, rocks and grass tufts (Jones 2000). Thus a reduction in plant cover is likely to have serious implications for soil carbon content and therefore functioning of communities at a local scale.

Higher levels of potassium were found in closed-canopy soil samples than open-canopy soil samples. Stokes (1999) suggested that low levels of potassium are explained by the removal of nutrient rich topsoil. Pienaar (2002) and Jones (2000) suggested that the

removal of plant cover on particularly flats leads to the removal of nutrients in the ecosystem.

While magnesium levels did not differ, the soil calcium content between open- and closed-canopy micro-sites in this study is in support of Marrs *et al.* (1989) who noted that calcium levels were greater in ungrazed or less grazed study sites, which confirm that litter accumulation is prevented when animals does grazed these sites.

The higher zinc levels in closed-canopy soil samples than in open-canopy soils were likely to be more attributed to local grazing activities at different parts of the landscape. The gradual increase in zinc levels until the the plateaux for both the Tafelberg and Folminkskop mesas could possibly be explained by a shale layer that is close to the soil surface on the plateaux. Buffelskop is a sandstone mesa comprising of a higher proportion of sandy soils and thus revealing lower zinc levels. The ostrich camp on the south-eastern flats of Buffelskop may explain the high zinc levels found at this study site due to the concentration of ostrich urine and dung pellets.

Open-canopy soil samples collected on the flats of Tafelberg mesa contained marginally higher manganese levels than closed-canopy soil samples. This may possibly be explained by the acidity of the soils. Unlike the sandstone Buffelskop mesa, the two dolerite capped mesas showed similar trends in manganese levels. Differences in soil manganese levels are possibly explained by differences in the parent material of mesas, since the soil texture was different between the dolerite and sandstone mesas.

Furthermore, the significant difference in boron levels between open and closed-canopy soils suggests that localized boron deficiency occurred (Galston *et al.* 1980) and element leaching from under individual plants is taking place on all the mesas (Jones 2000). It is also possible that calcium may play a role in influencing boron levels found at all mesas (Pais and Jones 1997). The soil pH, however, did not different between both open- and closed-canopy soil samples.

4.5.3 Soil texture

Soil texture refers to the particle size distribution of the inorganic component of soils and is a property of soil that is not readily prone to change (Brady 1990). It forms part of the

physical properties of soils, which affect soil water availability and can also determine the spatial pattern of vegetation (Olsvig-Whittaker *et al.* 1983) and plant growth (Greenland 1981). The sandy soils, with associated low soil organic matter, will have gradually reduced levels of base-forming cations thereby inducing soil acidity (Buckman and Brady 1969; Brady 1990). There was relatively high soil organic matter on the plateaux and slopes of all three mesas that in turn could have contributed to the formation of acids in the soil. The relatively higher clay content at the slopes and plateaux of dolerite-capped mesas was probably a contributing factor to the high pH values of soils from these sites. Clay and soil organic matter have a high cation exchange capacity and are able to adsorb base-forming cations more readily than the relatively larger soil particles such as sand and silt (Brady 1990). High animal activity on the flats may contribute to high pH values. The plateau of Tafelberg is comprised of a dolerite cap and mudstone slopes. Accumulations of silt in pans and depressions might be a strong contributing factor to the high silt and clay levels found on the plateaux of the Tafelberg and Folminkskop mesas (Rutherford and Westfall 1994). Consequently, water tends to accumulate at these sites due to the dolerite cap as the latter makes it difficult for water to infiltrate its hard surface.

4.5.4 Soil surface condition

Environmental changes and grazing impacts are potential threats to the conservation of soil condition and it is clear that soils in the Middelburg District of the Eastern Cape, have been affected. At a landscape level, evidence points that flats were degraded surrounding the mesa. Degradation or destruction of plant cover leads to a disruption of soil stability, infiltration, and nutrient status (Albaladejo *et al.* 1998). Dias *et al.* (1994) noted that as soil organic matter decreases, soil physical properties are degraded. We know that soil and plant damage in arid and semi- arid areas is not easily repaired (Milton *et al.* 1994), it is therefore important to understand how soil surface disturbance affects soil quality. The results clearly indicated higher soil stability and infiltration on the flats of Tafelberg mesa compared to the plateau. However, soil stability was predicted to be lower on the mesa flats and slopes, but this was not found in this study. Factors responsible for the decrease in soil stability might be trampling effects during animal activity and general erosive features. A study conducted on the flats indicated a high percentage of trampling on *Themeda triandra* seedlings. Chapter three also indicated high dung pellet values on the flats and slopes, which may contribute to the degradation

process in terms of patchiness of bare soil and less litter cover. Low soil nutrients, such as carbon and potassium, may also contribute to these degradation processes. Degradation or destruction of plant cover causes carbon levels to decrease in soils (Albadejo *et al.* 1998; Brady 1990).

4.6 Conclusion

In southern African semi-arid systems, soils have been shown to play a role in determining transitions between vegetation types (Palmer *et al.* 1988) as well as between different plant communities or assemblages (Smitheman and Perry 1990). This study explored whether changes in soil have resulted from land use in the Middelburg District. The results suggested that carbon, phosphorus, calcium magnesium, copper and manganese levels in soils at different parts of the landscape are likely to explain vegetation changes between habitats as was found by Pienaar (2002). Secondly, land use (open- vs closed-canopy cover) was responsible for some changes in soils. Soil carbon was one of the elements that was responsible for changes in soils at a local scale (open-and- closed canopy) due to land use and also explained vegetation changes between habitats (flats, slopes, plateaux) at a landscape scale. Changes in only soil potassium, zinc and boron elements were actually a consequence of local scales due to land use.

The flats of the mesas have been extensively used for many decades as rangelands. This study demonstrated that high levels of phosphorus, calcium and magnesium characterize the flats in the presence of low amounts of carbon, copper, zinc and manganese. These soil properties may have been accelerated by factors such as bad veld management and over-utilization (Acocks 1953; Roux and Opperman 1986; du Preez and Snyman 1993).

Mesas may play an important role in potentially contributing nutrients to the surrounding flats through a process of erosion. Soils of the upper slopes and the plateaux, characterized by high silt and clay levels, of the three mesas clearly had higher carbon content. Carbon content, primarily through the provision of litter, forms the largest constituent of soil organic matter.

Restoration efforts need to be concentrated on the flat areas in the Middelburg District, in order to increase canopy-cover of desirable plant species. Dung pellet seeding (i.e. the germination of seed found in dung pellets) may be used as a possible restoration technique to restore these degraded areas, given the characteristic soil properties demonstrated in this study.

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Chapter 5: What grows from dung pellets – implications for degraded areas in the Karoo

5.1 Abstract

The possible role of herbivores and livestock as seed dispersers was investigated by determining successful seedling emergence and the subsequent identification of mature plants using a dung seed germination method. The idea was to investigate if dung pellets can be used as a source of propagules in restoration programmes of degraded areas. Dung pellet samples were collected from the SE and NW study sites on the plateau, slopes and surrounding flats of Tafelberg mesa. A total of 22 taxa were identified to species level to have germinated from dung pellet samples. A high number of total seedlings (222 seedlings) germinated from dung pellets collected on the flats, compared to the lower number of seedlings recorded from dung pellets collected on the plateau (10 seedlings). Dung pellets from the flats produced the highest number of different plant species. When the relative abundance of plant species germinated from dung pellets was compared to that of the same species recorded in a study of above-ground vegetation and that of the soil seed bank. Several plant species were recorded in the dung seed germination experiment that were not present in the soil seed bank recorded in each habitat, inferring the important role that herbivores play in dispersal of seeds. The fact that palatable grass species were found in dung pellets suggests that grazing animals in the Middelburg District have the potential to at least maintain populations of these plants in places where they regularly gather to feed. This contributes to pasture regeneration in the affected area, hence a process of restoration.

5.2 Introduction

Animal droppings play an important role in the environment since they are implicated in a variety of ecosystem functions, including seed dispersal and the concentration of nutrients into patches (Murray 1995; Nel 1998; Janzen 1984). These dung pellet accumulations can also cause changes in vegetation, by enabling annual endozoochorous species to replace perennial grasses (Malo and Suarez 1995). Many endozoochorous Karoo species are associated with intensive grazing and other forms of disturbance (Dean and Milton 1999). Herbivores are important dispersers and may play an important role in the reclamation of degraded areas in the Nama-Karoo Biome. However, a lack of knowledge about which species are dispersed by animals, remains a hurdle in attempts to restore degraded landscapes.

Studies on endozoochory in the arid zone of Southern Africa, have focused primarily on the Kalahari Savana biome (Hoffman *et al.* 1989; Leistner 1961; Miller 1996), although more recently, Milton and Dean (2001) investigated the incidence of endozoochory by dissecting and germinating seed from dung pellet samples taken from a range of domestic and wild mammals in the South African Karoo shrublands and Kalahari savanna. Endozoochorous dispersal and the deposition of dung pellets in areas of small disturbances may play a role in veld revegetation in affected areas (Malo and Suarez 1995). One can safely assume that seed dispersed within dung pellets could benefit re-establishment of vegetation cover in disturbed areas. However, in arid areas, climate, especially rain frequency and amount, also plays an important role in seed dispersal, since certain plant species retain seeds in woody capsules that open only when sufficiently dampened by rain (hygrochastic), enabling release of seeds to coincide with rainfall events (Hartmann 1991). Since ranching has increased in intensity over the past century, domestic livestock such as sheep and cattle have replaced many indigenous animals. The impacts of replacing indigenous animals with introduce livestock on the dispersal biology of the Karoo species is not yet determined.

The aim of this experimental study was to assess firstly if successful seed germination from dung pellets (collected on- and off- Tafelberg mesa) takes place and secondly, identify which species are dispersed in dung pellets. With this study of dispersal process, it is expected that the results will find useful benefits if this process could be used in re-seeding attempts of degraded areas.

5.3 Method

5.3.1 Determination of endozoochory using a germination method

Dung pellets were sampled within three randomly placed 1x1 m quadrates in each vegetation plot (see Chapter two for an outline of the permanent study sites). Dung pellet samples were then pooled and mixed thoroughly to represent one integrated replicate for that vegetation plot. Thus, three vegetation plots were sampled for each permanent study site on the flats, slopes and plateau of the Tafelberg mesa.

Forty-six seedling trays (16 x 23 x 5 cm) were first layered with old newspaper to prevent water loss and then filled up to three quarters full with a general potting Kirstenbosch General Mix (KMG) mixture obtained from the Kirstenbosch Botanical Gardens in Cape Town. The dung pellets from each vegetation plot was gently broken up until it could be evenly sowed over the soil. Each tray was then topped with a 2-millimeter layer of KGM potting soil. The soil was sprayed with Captan fungicide to reduce fungal infection. Trays were then randomly placed out on a 5 centimeter layer of gravel to keep the trays level and to prevent water logging below the trays. An irrigation system was set up to mist the trays each day at 6:00 pm for half an hour. As seedlings emerged, they were marked with a needle to prevent re-counting. Germination was assessed every third day for the first month of the experiment. After one month, recordings were done on a weekly basis until five months after the initiation of the experiment.

Mature seedlings (approximately 12 cm in height) were then potted out into individual growing pots (13 x 12.5 cm) so that they could reach adult stage for identification. Mature seedlings were categorized into monocotyledons, dicotyledons, non-succulent dicotyledons and succulent dicotyledons. These plants were then identified to the level of family, genus and, where possible, to species level.

5.3.2 Determination of relative abundance (% RA)

Data obtained from studies of soil seed banks (Jones 2000) and above ground vegetation (Pienaar 2002) were compared to the data obtained in this study. The percentage relative abundance (RA) of each plant species per habitat was calculated using the following formula:

$$\begin{aligned} \text{RA (\%)} &= \frac{\text{No. of spp. } \gamma \text{ per habitat}}{\text{Total plant species per habitat}} \times 100 \\ &= \text{RA (\%)} \end{aligned}$$

5.4 Results

5.4.1 Seedling emergence and mortality

The majority of seeds germinated from dung pellets within the first two months after planting (Figure 5.1). Dung pellets taken from the flats had the highest number of seedlings (222 seedlings) germinated while low germination rates were recorded for the plateau. High seedling mortality was recorded from trays representing samples taken from the flats and slopes of Tafelberg (Figure 5.2).

At the time of this write-up, 18 genera from nine plant families (belonging to two Monocotyledonae and seven Dicotyledonae respectively) were identified during the germination trial (Table 5.1). A total of 26 individual plants still needed to be identified to a species level because they had not yet flowered. At least 21 individual plants of these unidentified species belong to the family Poaceae. Notably, however, some of these plants could also be duplicates of previously recorded plant species and, therefore, likely that the final number of species may only be moderately higher than represented in this chapter.

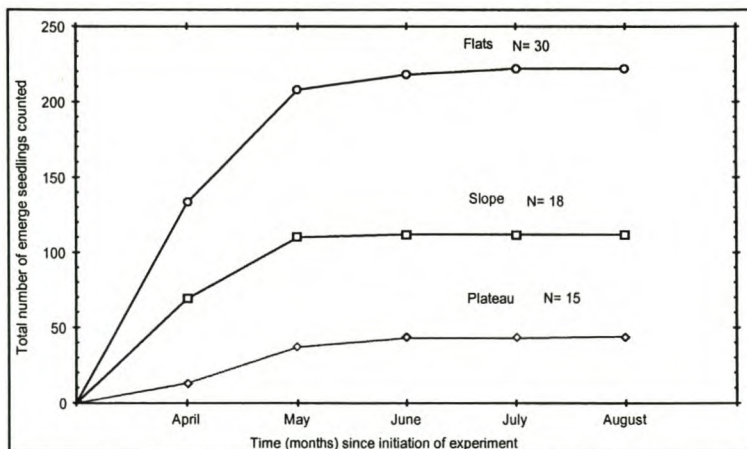


Figure 5.1: Cumulative counts of seedlings emerging from dung pellets collected from three habitats on- and off- Tafelberg mesa. Sample size N= number of seedling trays

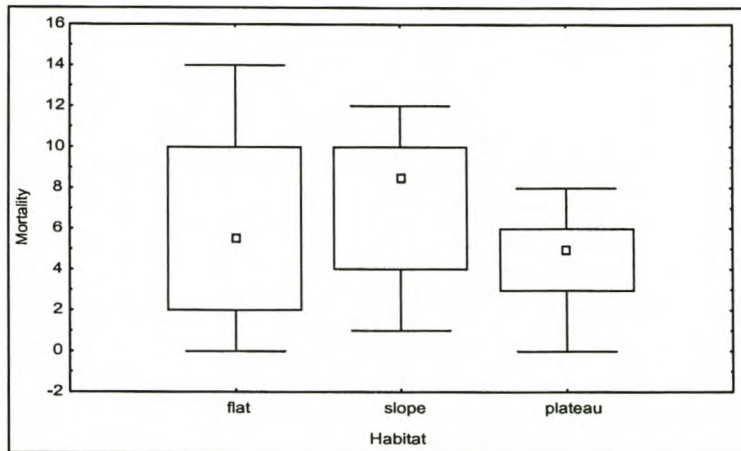


Figure 5.2: Seedling mortality from dung pellets germination trials for the three different habitats (flat, slope and plateau) on- and off- Tafelberg.

Table 5.1: List of families, with the number of genera and species identified to date of writing. The “unidentified species” are those, as yet unidentified to species level, that are possibly duplicates, but which may be separate species. It also includes those plants that have not been identified categorically to family level.

Family	Number genera	# definite species	# plants still unidentified	Total possible
MONOCOTYLEDONAE (2 families)				
Cyperaceae	5	5	21	46
Poaceae	1	1		1
Subtotal	6	6	21	27
DICOTYLEDONAE (7 families)				
Aizoaceae	1	1		1
Anacardiaceae	1	1		1
Asphodelaceae	1		1	1
Asteraceae	3	3	1	3
Cayophyllaceae	1	1		1
Chenopodiaceae	1	1	1	2
Mesembranthemaceae	5	5	2	7
Sub totals	12	12	5	17
Monocot unknown family	1			
Dicot unknown family	2			
Totals	18	18	26	44

5.4.2 Seed germination in relation to habitat

The dung pellet samples collected on the flats of the Tafelberg mesa (north-western and south-eastern) had collectively 19 different plant species compared to the nine and two plant species from dung pellets of the slopes and plateau (Table 5.2). Of the 19 identified plant species germinated from dung pellets on the north-western and south-eastern flats of the Tafelberg mesa, six species were common to both sites while the rest was flat specific. For example, amongst the grasses *Aristida sp* and *Eragrostis chloromelas* were common to both the north-western and south-eastern flats while *Oropetium capense* germinated from dung pellets that was only collected on the north-western flat of the Tafelberg mesa.

Samples collected on the slopes showed a higher variation of germinated plant species germination. Of the nine different plants germinated from dung pellets on the north-western and south-eastern slopes of the Tafelberg mesa, only one specie (*Eragrostis chloromelas*) was common to both sites while the rest was slope specific. Five plant species (*Aridaria noctiflora*, *Eragrostis obtusa*, *Rhus burchelli*, *Trichodiadema rogersiae* and *Pentzia incana*) were identified from dung pellets on the south-eastern slope and a further three species (*Drosanthemum duplessiae*, *Herniaria erckertii* and *Eragrostis bicolor*) from dung pellets collected on the north-western slope of the Tafelberg mesa.

The grass *Urochloa panicoides* and bulb (*Bulbine sp.*) were the only two plants germinated from dung pellet samples collected from sites on the plateau of the Tafelberg mesa.

5.4.3 Characteristics of endozoochoric flora

Shrubs (seven taxa) were well represented, followed by grasses (six taxa), succulents (five taxa), forbs (two taxa) and one annual specie (Table 5.3). These taxa had seed sizes ranging from 0.2 to 1.5 millimeters in diameter. Fruit types varied and known dispersal agents ranged from passive to water, wind, birds and herbivores (Table 5.3). The results also included plant species not previously known to be dispersed by herbivores.

Table 5.2: Number of seedlings of species identified to date of writing. Data also represents the locality (flats, slopes and plateau) from which dung pellet samples were removed on- and off- Tafelberg mesa.

Genus or species	Number of plants/ habitat				
	NW flat	NW slope	Plateau	SE slope	SE flat
<i>Aridaria noctiflora</i>	1			2	
<i>Aristida</i> sp.	2				1
<i>Bulbostylis humilis</i>					1
<i>Bulbine</i> sp.			2		
<i>Chenopodium mucronatum</i>	1				
<i>Chenopodium</i> sp.	3				3
<i>Drosanthemum duplessiae</i>		1			
<i>Eberlanzia ferox</i>					2
<i>Eragrostis bicolor</i>	4	2			
<i>Eragrostis chloromelas</i>	4	2		4	1
<i>Eragrostis obtusa</i>				1	1
<i>Galenia secunda</i>	2				
<i>Herniaria erckertii</i>	1	1			4
<i>Oropetium capense</i>	5				
<i>Pentzia incana</i>	2			2	3
<i>Pentzia</i> sp.					1
<i>Phyllobolus splendens</i>	1				
<i>Phymaspermum parvifolium</i>	1				
<i>Rhus burchelli</i>	2			2	
<i>Roseneae humilis</i>	1				
<i>Trichodiadema rogersiae</i>	3			4	1
<i>Urochloa panicoides</i>			1		
Species Richness	15	4	2	6	10

Table 5.3: Characteristics of plant species identified from seedlings emerging in dung pellets samples of mammals foraging on- and off- Tafelberg mesa with alien species typed in bold face.

Plant Genus	Family	Life-form & habitat	Fruit type & dispersal agent	Seed Diam. (mm)
<i>Aridaria noctiflora</i>	Mesem.	Succulent, flats	Capsule, hydrochorous ¹	1.5
<i>Aristida sp.</i>	Poaceae	Grass, flats	Passive, herbivore	
<i>Bulbostylis humilis</i>	Cyperaceae	Annual, flats	Plumed, wind ²	
<i>Bulbine sp.</i>	Cyperaceae	Succulent,		
<i>Chenopodium mucronatum</i>	Chenopodiaceae	Forbs, flats	Leaves, herbivore ³	1.0
<i>Chenopodium sp.</i>	Chenopodiaceae	Forbs, flats	herbivore	
<i>Drosanthemum duplessiae</i>	Mesem.	Succulent, flats	Capsule, hydrochorous ⁴	0.3
<i>Eberlanzia ferox</i>	Mesem.	Succulent, flats	Capsule, hydrochorous ⁵	
<i>Eragrostis bicolor</i>	Poaceae	Grass, flats, drainage lines	Passive, herbivore ⁶	0.3
<i>Eragrostis chloromelas</i>	Poaceae	Grass, flats, slope	Passive, herbivore ⁷	0.3
<i>Eragrostis obtusa</i>	Poaceae	Grass, flats	Passive, herbivore ⁸	0.2
<i>Galenia secunda</i>	Aizooideae	Shrub, flats	Small capsule, passive ⁹	1.0
<i>Herniaria erckertii</i>	Cayophyllaceae	Flats		
<i>Oropetium capense</i>	Poaceae	Grass, flats	Passive, herbivore ¹⁰	
<i>Pentzia incana</i>	Asteraceae	Shrub, flats	Unwinged achenes, passive ¹¹	1.0
<i>Pentzia sp.</i>	Asteraceae	Shrub, flats	Unwinged achenes, passive	1.0
<i>Phyllobolus splendens</i>	Mesem.	Succulent, flats	Capsule, hydrochorous ¹²	1.5
<i>Phymaspermum parvifolium</i>	Asteraceae	Shrub, drainage line	Fleshy, wind ¹³	
<i>Rhus burchelli</i>	Anacardeaceae	Shrub, mesas, drainage line	Birds ¹⁴	
<i>Rosenia humilis</i>	Asteraceae	Shrub, flats	Wind ¹⁵	
<i>Trichodiadema rogersiae</i>	Mesem.	Shrub, flats	Capsule, hydrochorous ¹⁶	
<i>Urochloa panicoides</i>	Poaceae	Grass, flats	Passive, herbivore ¹⁷	

^{1,5} Le Roux *et al.* (1994); ^{7,17} Moffett (1997); ^{6,8,10} Gibbs *et al.* (1990); ² Gordon-Gray (1995);

^{14,13} Shearing (1994); ^{3,4,11,12,16} Milton (2001); ^{9,15} Pienaar (2001)

5.4.4 Relative abundance (% RA): dung pellet seed germination, vegetation analysis and soil seed bank

No single habitat on the Tafelberg mesa produced more relative abundant seeds from dung pellets ($p = 0.163$; $df = 2.63$; $F = 1.8$) (Table 5.4). There was also no correlation in relative abundance between the seeds that germinated from the dung pellet samples and those from the vegetation analysis ($r = 0.15$; $n = 66$; $p = 0.234$) or soil seed bank ($r = 0.07$; $n = 66$; $p = 0.585$).

Several plant species (*Aristida sp*; *Chenopodium sp*; *Pentzia sp*; *Aridaria sp*; *Eragrostis bicolor* and *Bulbine sp*) were recorded in the dung pellet seed germination experiment that was not present in the soil seed bank recorded in each habitat. On the other hand, *Eragrostis chloromelas* and *Drosanthemum duplessiae* were present in the soil seed bank, but not in the dung pellet germination trials.

Pentzia incana was relatively abundant on the flats and slopes of the Tafelberg mesa for all three investigations (dung pellet seed germination, vegetation analysis and soil seed bank) compared to the plateau. High relative abundant values were found for *Bulbine sp.* and *E. chloromelas* on the plateau of the Tafelberg mesa in the dung pellet seed germination experiment.

Table 5.4 : Table indicates relative abundance (% RA) of each plant species per habitat. Numbers 1, 2, and 3 indicates the following: 1= RA recorded for species in dung pellet emergent study; 2= RA recorded of species in above ground vegetation study (Pienaar, 2002); 3= RA recorded for species in below-ground vegetation study (Jones, 2000).

Genus or species	Relative Abundance (%)								
	Flats			Slopes			Plateau		
	1	2	3	1	2	3	1	2	3
<i>Aridaria noctiflora</i>	0.5	0.1	0	1.2	0	0	0	0	0
<i>Aristida sp.</i>	1.4	0	0	0	0	0	0	0	0
<i>Bulbostylis humilis</i>	0.5	0.3	3.2	0	0	2.2	0	0	0.7
<i>Bulbine sp.</i>	0	0	0	0	0	0	6.5	0	0
<i>Chenopodium mucronatum</i>	0.5	0	0	0	0	0	0	0.1	0
<i>Chenopodium sp.</i>	2.7	0	0	0	0	0	0	0	0
<i>Drosanthemum duplessiae</i>	0	0.7	1.2	0.6	0	0.1	0	0	0
<i>Eberlanzia ferox</i>	0.9	3.4	0.2	0	0	0	0	0	0
<i>Eragrostis bicolor</i>	1.8	0.1	0	1.2	0	0	0	0	0
<i>Eragrostis chloromelas</i>	2.3	0.1	0	3.6	1.9	0	0	5.6	0
<i>Eragrostis obtusa</i>	0.5	0.9	1.8	0.6	0.2	1.7	0	0.4	0.1
<i>Galenia secunda</i>	0.9	0.3	0.4	0	0	0	0	0	0
<i>Herniaria erckertii</i>	2.3	0	0.2	0.6	0	0.7	0	0	0
<i>Oropetium capense</i>	2.3	0.4	0.4	0	0	0	0	0	0.1
<i>Pentzia incana</i>	2.3	3.7	4.1	1.2	2.8	9.7	0	0	0.7
<i>Pentzia sp.</i>	0.5	0	0	0	0	0	0	0	0
<i>Phyllobolus splendens</i>	0.5	0.4	5.4	0	0	0.1	0	0	0
<i>Phymaspermum parvifolium</i>	0.5	0.2	0	0	0	0	0	0.1	0
<i>Rhus burchelli</i>	0.9	0	0.04	1.2	3.1	0.4	0	0	0.1
<i>Rosenia humilis</i>	0.5	0	0	0	0	0	0	0	0
<i>Trichodiadema rogersiae</i>	1.8	0.4	0.5	2.4	0.2	0.2	0	0	0
<i>Urochloa panicoides</i>	0	0.1	0	0	0	0	3.2	0	0

5.5 Discussion

Over decades, arid and semi- arid areas have encroached into extensive areas of once productive farm and grazing land, creating bare patches and dramatically reducing productivity. According to Nel (1998), feasible dung seeding techniques have been introduced to stabilize or improve these serious situations. However, these techniques were found to be generally too expensive to implement on a large scale and were generally beyond the resources of local farmers. Dung pellet seeding could potentially be seen as an economical and efficient technique that does not detrimentally affect the current productive land use. With this technique a farmer can use livestock as his “labor force” to efficiently and economically re-vegetate his farmland, veld and pastures with selective plant species. The role of animal droppings in the environment is vast, covering aspects from territory marking to habitat use, nutrient cycling and most of all seed dispersal.

5.5.1 Seed germination from dung pellets

The results from this study demonstrated that seed could be successfully germinated from dung pellets collected from herbivores in the Middelburg District. Clearly, many seeds are not damaged in the process of digestion or in the dung pellets, due to pathogens and/or seedeaters. The fact that seed successfully germinated suggests some species not only withstand these negative impacts, but also by passing through the animals, may gain great benefits for germination.

Despite that fact that the majority of seeds germinated within the first two months after planting, seeds can survive and germinate in dung pellet accumulation as old as 30 months (Appelgate *et al.* 1979; Wicklow and Zak 1983). Dung pellet seeding should, however, be used with caution where the risk of spreading alien invasive species is higher than the spreading of indigenous species or where livestock spend part of their time in planted pastures. In this study three alien species (*Urochloa panicoides*, *Chenopodium mucronatum*, and another *Chenopodium sp.*) were recorded from dung pellets. Furthermore, the high seedling mortality may have been related to conditions during the experiment and not related to habitat variation.

5.5.2 Dung pellet seed germination in relation to habitat

More plant species germinated from dung pellets collected on the flats than those sampled from the slope and plateau of the Tafelberg mesa. This might reveal the important role that herbivores play in seed dispersal in relation to habitat preference (Murray 1995).

The high percentage relative abundance of *E. chloromelas* (decreaser species) on the plateau of Tafelberg can be attributed to the fact that this habitat is not accessible to livestock and herbivores. The steep slopes (cliffs) make it almost impossible for animals to move up to the plateau and the lack of water points on the plateau are another reason why so few animals move to the plateau. Hence, these hypothesize less disturbed habitats may provide conservation islands for these certain plant species (Hodgson and Illius 1996; Jones 2000; Pienaar 2002).

The grasses *Aristida* sp., *Eragrostis bicolor*, *Eragrostis chloromelas* and *Eragrostis obtusa* are palatable species (Pienaar, pers com). The fact that they were found in dung pellets suggests that domestic livestock and wild herbivores have the potential to maintain or increase populations of these plants in places where they regularly gather to feed (Milton and Dean 2001). Cattle and sheep, therefore, provide good and ample opportunities for long-distance dispersal of these species and other seeds (Janzen 1982). The dispersal of endozochorous species to different habitats is important in the build-up of seed banks associated with small disturbances, and may play a role in pasture regeneration in the affected area (Malo *et al.* 1995).

5.5.3 Comparisons dung pellet seed germination, vegetation analysis and soil seed

Soil seed banks in the Middelburg District exhibited differences between the flats, slopes and plateaux (Jones, 2000). Furthermore, the data also suggested that the low-lying rangelands are degraded since many of the species recorded in the soil seed banks were annuals or unpalatable shrubs (Jones 2000).

Ten of the plant species recorded in dung pellets in this study were common with Jones (2000) list of species (97 plant species) found on the south-eastern and north-western flats. Three species found in the dung pellet study were not reported in Jones (2000) experiment, but were found to be present in the vegetation study on the flats surrounding

the mesa. The three species were *Aridaria noctiflora*, *Galenia secunda* and *Phumasperrum parvifolium*. Out of Jones (2000) species list of 115 species, 12 species from this study were common with her species list, but were found in different habitats. Six species recorded in this study were not common to her species list. The sixth species was *Urochloa panicoides* that was found on the plateau of Tafelberg. This could suggest that either the species was not recorded during the soil seed bank sampling or these species are only dispersed in dung pellets, therefore present in the soil seed bank. Livestock or herbivores may be important dispersers for these species (Janzen 1984; Murray 1995; Nel 1998; Zedler and Black 1992).

Several plant species were recorded in the dung pellet study, but were not present in the soil seed bank nor recorded in vegetation study at the same sites. This indicates the important role that herbivores play in dispersal of seeds (Murray 1995; Nel 1998; Milton 1992; Janzen 1984). *Aristida sp.*, *Chenopodium sp.* and *Pentzia sp.* germinated from the dung pellets, but were not recorded in either the vegetation or soil seed bank studies at the same sites.

5.5.4 Ecosystem management and restoration

Jones (2000) argued that the flats showed no great promise for restoration potential based on its soil properties. In fact, the habitat-use study (Chapter 3) identified that degraded flats but also a higher dung pellet density and a higher percentage of bare soil patches. Is it then suggested that we must avoid the reclamation of degraded areas in the Nama-Karoo Biome? One of the answers to restoration efforts in the Karoo probably lies in the successful germination of seed from dung pellet samples.

This study provided insight about which plants species are dispersed by animals on- and –off the Tafelberg mesa, implying that these plants could be valuable ‘tools’ towards ecosystem functioning and restoration efforts. The results demonstrated that it is possible to successfully germinate seeds from dung pellet samples. The fact that a more diverse assemblage plant species, including several palatable grasses, germinated from dung pellets collected on the flats than those sampled from the slope and plateau of the Tafelberg mesa, suggests that herbivores play an important role in seed dispersal and exhibit the potential to maintain or increase populations of these plants in places where they regularly gather to feed.

In conclusion, this study demonstrated that dung pellet seed germination is a possible strategy to identify desirable plant species for the future restoration of degraded veld. The advantage of seed germination from dung pellets is that it is potentially simple, easily implemented and cost effective. Future research is needed for further assessment of the effectiveness of such a technique in restoration.

5.6 References

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Chapter 6: Conclusions and recommendations for future studies

6.1 Introduction

The overriding aim of this study was to determine if mesas act as conservation islands that have undergone less degradation than surrounding flats. This study incorporated altitudinal and habitat gradients associated with three mesas and their surrounding flats, focusing primarily on soil composition and characteristics. The study also investigated whether dung pellets can be used as an indicator of habitat use by herbivores and the degradation associated with overgrazing. Dung pellets collected from habitats on- and off- Tafelberg mesa, were used in a germination experiment to determine viable seed content. The aim of this study was to determine whether dung pellet seeding could be used as a source of propagules in restoration programmes of degraded areas.

6.2 Dung pellets on- and off- the mesas.

An assumption not tested in this study was if dung pellets could be used as a surrogate of animal counts. It is important to note that dung pellets are a short-term indicator of herbivore habitat use (less than 5 years, depending on the rate of dung pellet decay), whereas degradation can take place over much longer time-spans (10-100 years). Current land use does not necessarily reflect past, longer-term land use. Dung pellet counts were highly variable on all habitats (flats, slopes, plateaux) sampled of all three mesas. When combining data, the overall dung pellet density for flats, slopes and plateaux did not show a clear pattern to confirm the hypothesis that present habitat use by grazers was less concentrated on the plateaux of mesas compared to the surrounding flats when data for each individual mesa was analysed, Tafelberg mesa was the only study site that provided evidence of significant lower differential dung pellet density on the plateau. This was the only mesa of the three studied that conformed to the hypothesis that mesas, with less accessibility are in essence "conservation islands", protected from grazing. The high mean dung pellet density on the plateaux and slopes of the smaller mesas, Folminkskop and Buffelskop is likely due to easier accessibility.

Bare patches were most common on the flats surrounding the three mesas. A link was made between the frequency of bare patches and trampling (Chapter 3). Bare patches are a good predictor of degradation and a significant positive correlation between bare soil and dung pellet density was obtained. Litter cover was also linked to areas with different degrees of bare soil. Where a high percentage of bare soil

occurred a low percentage of litter cover was evident. The intercorrelation between dung pellets and other parameters such as bare soil associated with degradation, suggest that measuring these parameters was a useful exercise to examine different habitat use by grazers.

Even though distinct patterns of habitat use by domestic livestock appeared to be the case, there were shortcomings to the method of dung pellet density. The method requires testing via, direct observations of exactly where the animals were going, where animals were absent and how long they spent at each site. The disadvantage of the direct observation method is that animals can be difficult to track in dense vegetation, introducing a significant amount of observer bias. Dung pellet counting has the potential to reduce such bias. Another problem encountered with this study was the failure to classify dung pellets according to origin (sheep, cattle, indigenous herbivores). This may introduce bias into the interpretation of the data set, as these different groups have different profiles and impacts on the landscape. Despite the pitfalls, the method does appear to have potential for rapid assessment of current habitat use by herbivores.

6.3 Soil composition on- and off- the mesas.

This study showed that degradation indicators (e.g. bare soil) could be correlated to soil physical and chemical properties. Physical factors such as soil texture and chemical factors such as soil carbon and potassium, all influence the hydrological characteristics of the soil and are therefore important for plant establishment and survival. This study showed variation in soil macro- and micro-elements between open- and closed-canopy micro-sites at different parts of the landscape with the aim of differentiating between local scales due to land use and landscape scales due to geomorphology. At the landscape scale or level, significant variations were observed in soil chemical and physical composition between the flats, slopes and plateaux of all mesas. Results of this study demonstrate that vegetation changes are better explained by landscape scales that include soil properties such as carbon, phosphorus, calcium magnesium, copper and manganese than by grazing effects. The flats surrounding all three mesas showed low levels of carbon and potassium. The high carbon levels found on the slopes and plateaux of all mesas are partly due to a higher density of emergent rock (which traps debris); denser plant canopy cover; as well as a lower intensity of grazing on the plateau and slopes (Chapter 3). It would have been preferable to get an idea of the nitrogen content of soils, since nitrogen can be a limiting factor in the maintenance and availability of carbon in soils.

It is therefore recommended that detailed tests of soil nitrogen content be undertaken and that these be compared with and correlated to soil carbon. Soil nutrients on the mesa slopes appeared to be at intermediate levels between the flats and plateaux of all three mesas. Differences in soil composition may have been accelerated by anthropogenic factors, such as bad veld management and overgrazing, which result in loss of overall plant cover and soil organic matter. Low soil nutrients on the flats will affect the nature and direction of future attempts to restore the flats. This study also found that at the landscape scale, soils from the mesas and their surrounding flats showed significant variations in soil texture such as sand, silt, clay and stone.

At the level of individual plants, micro-site variations between open-canopy (between shrubs) and closed-canopy (under shrubs) micro-habitats were found to be significant for potassium, zinc and boron elements, which were hypothesized to be a consequence of local scales due to land use. Zinc and boron levels of soils from open-canopy samples were consistently lower than from the closed-canopy samples. Potassium content was lower for open-canopy samples than for closed-canopy samples. The implication is that when perennial plant cover is removed, which is definitely the case on the flats (Pienaar 2002; Jones 2000), nutrients are also removed from the systems.

Desirable plant species, which are able to germinate, establish, and most importantly, survive in open-canopy spaces, especially on sandy soils (flats) with low soil organic matter and nutrient levels, must be identified for an attempt at the restoration of the flats. Soil stability on the mesa slopes was expected to be lower than on the flats and plateau (due to slope angle), although findings using the Tongway and Hindley (1995) method, suggested otherwise. As expected, infiltration rate was found to be high on the flats of both mesas.

A potential mechanism to improve soil nutrient status of the region could be initiated through reduction or withdrawal of grazers in selected camps for certain periods to allow optimal flowering, seed set and establishment of desirable plant species. This could in turn increase plant cover levels. This would definitely have an impact on the daily earnings of most of the land farmers, but the long-term benefits of improved veld condition may well outweigh these losses. The problem associated with this recommendation is that visible signs of veld improvement may take longer than the average life span of the farmer. Also, if the veld has deteriorate beyond a critical

threshold, it may never recover without active intervention (e.g. soil amendments and re-seeding).

6.4 Dung pellet seed germination from on- and off- the Tafelberg mesa.

The dispersal and deposition of these endozoochorous species through dung pellets, plays an important role in veld revegetation in degraded areas. Plant species found in dung pellets (e.g. *Aristida* sp.), are well adapted for dispersal by livestock and herbivores. Higher seedling percentages were recorded for dung pellets collected on the flats than for the plateau. Seeds germinated represented a variety of palatable grass and shrub species. *Aristida* sp., *Chenopodium* sp. and *Pentzia* sp. were found in dung pellets, but were not recorded in parallel soil-seed bank and vegetation studies.

Dung pellet samples were not sampled during different seasons so this study was therefore not able to detect seasonal patterns or to detect correlations with rainfall. Rainfall in the area is very unpredictable. The germination method used in this experiment exposed seeds to the variable day: night temperatures associated with the Stellenbosch climate, but may not have provided ideal germination conditions for all species. Some seed species require exposure to low temperatures to break their dormancy, or they may require higher temperatures for germination. Dung pellet samples for the germination trial were not collected simultaneously, therefore their seed content were not directly comparable. Time to flowering is species dependent and although many plant species were readily identifiable to at least family level, within a few months of germination, this was not possible in a number of other instances. Grasses are especially tricky as they are morphologically very similar prior to flowering, it is therefore recommended that germination trials be conducted over a period of not less than one year. This study demonstrates that dung pellet seed germination has a significant potential to identify desirable plant species for future restoration of degraded flat areas.

In conclusion, It appeared that dung pellet density did not clearly turn out to be an indicator of habitat use, but showed that dung pellet density was greater in areas where accessibility was easier to the livestock and herbivores. The fact that a correlation was found between dung pellet density, bare soil and litter cover, suggest that it could possibly be related to degradation. Distinct soil nutrient variations differ considerably at a landscape scale due to its geomorphology. Primary soil habitat differences were linked to soil organic matter content which was found to be low on

the flats relatively to the slopes and plateau; and; low open-canopy micro-sites relatively to closed-canopy sites of all the mesas. Soil parameters indicate possible relationships with degradation. Dung pellet seed germination has a significant potential to be used as a future restoration technique for degraded veld conditions.

6.5 References

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